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Effect of Modeling Instruction on Concept Knowledge Among Ninth Grade Physics Students

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COLLEGE OF EDUCATION

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Doctoral Study Submitted in Partial Fulfillment
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Abstract

A basic knowledge of physics concepts is the gateway to success through high-paying careers in science, technology, engineering, and mathematics (STEM). Many students show little understanding of concepts following traditional physics instruction. As an alternative to current lecture-based approaches for high school physics instruction, Piaget's theory of cognitive development supports using real scientific experiences to lead learners from concrete to formal understanding of complex concepts. Modeling instruction (MI) is a pedagogy that guides learners through genuine scientific experiences. This project study analyzed the effects of MI on 9th grade physics students' gains on the test measuring mastery of physics concepts, Force Concept Inventory (FCI). A quasi-experimental design was used to compare the FCI scores of a traditional lecture-taught control group to a treatment group taught using MI. A *t* test $t(-.201) = 180.26$, $p = .841$ comparing the groups and an analysis of variance $F(2,181) = 5.20$ comparing female to male students indicated MI had no significant positive effect on students. A partial eta squared of the effect size showed that 5.4% of the variance in FCI gains was accounted for by gender, favoring female participants for both groups. The significant relationship between content and gender bears further inquiry. A lesson plan guide was designed to help teachers use computer simulation technology within the MI curriculum. The project promotes positive social change by exploring further ways to help adolescents experience success in physics at the beginning of high school, leading to future success in all STEM areas.

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Dedication

This paper is dedicated to my late father, P. David Ditmore, who taught me that knowledge can never be taken away, and an education will open doors throughout one's entire life. I have learned that education is really about becoming a better, more informed observer of the universe. It is a living experience, and those doors are a part of the experience.

Acknowledgments

Thank you deeply, my wife Larissa, who has stood by me through thick and thin. I thank Dr. Smeaton for his patience and expertise, and the young professional educators in the classroom trenches who inspired this study.

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Section 1: The Problem

Introduction

Since the end of the Cold War era, American students have shown a general lack of interest and ability in pursuing career paths in science, technology, engineering, and mathematics (STEM) fields (Maltese & Hochbein, 2012). Global data have shown American students lagging in mathematics and scientific reasoning skills when compared to the rest of the world (National Center for Education Statistics [NCES], 2012), intensifying concerns about U.S. STEM education. In the 21st century, a large number of students are needed to pursue STEM careers. The United States Bureau of Labor Statistics (BLS, 2011) has determined about 2.5 million introductory STEM jobs will be available over the next decade. Yet, too few people are currently prepared to enter the STEM workforce (Maltese & Hochbein, 2012; Sadler, Sonnert, Hazari, & Tai, 2012).

A continued shortfall in projected STEM professionals in the United States is the result of two trends. First, only 8% of college degrees in America are awarded in STEM, and, second, the fastest growing areas of the workforce in the United States are in careers that require STEM skills (United States Department of Commerce, Economics and Statistics Administration [U.S. ESA], 2011). Most of the highest paying jobs in the country require an expert level of STEM skills, and one third of all jobs will be STEM-related by 2016 (Breiner, Harkness, Johnson, & Koehler, 2012; Rothwell, 2013). Furthermore, the U.S. ESA (2011) reported that women, while accounting for nearly 48% of the total United States workforce, hold only 24% of STEM jobs.

These jobs will be among a majority of the top-paying jobs available for new bachelor's graduates. A salary study conducted by the National Association of Colleges and Employers (NACE, 2014) indicated that 4-year engineering degree awardees were offered the highest average starting salaries of all bachelor's degree holders. All but four of the 97 STEM job occupations, accounting for more than 8 million jobs nationwide (NCES, 2012), have wages above the national average of $43,460 (BLS, 2011; NACE, 2014; Terrell, 2007). At an average annual salary of $77,880, employees with STEM degrees earned nearly 70% more money than the national average (BLS, 2011; Melguizo & Wolniak, 2012). The projected STEM job growth of 17% is nearly double the projected non-STEM job growth (U.S. ESA, 2011). As many as 68% of STEM employers have reported they were unable to find enough qualified employment candidates (BLS, 2011; NCES, 2012; Terrell, 2007). By the year 2018, 1.2 million high-paying STEM positions will go unfilled in the United States (Rothwell, 2013).

Despite the outcry of policy makers for STEM education improvement, educational reform in STEM has advanced slowly (Breiner et al., 2012). Low achievement in introductory science classes is the primary reason high school students are too discouraged to pursue careers in STEM fields (National Center for Science and Engineering Statistics [NCSES], 2012). Introductory physics is the foundation of all of the sciences and has traditionally been the cause for many students to exit from a STEM career path (Brewe, Traxler, de la Garza, & Kramer, 2013). Many high school physics students, particularly female students, find physics interesting and enjoyable but difficult to relate to their lives and futures (Quinn & Lyons, 2011; Sadler et al., 2012). American colleges experience a low enrollment rate in physics, with a significantly lower ratio of women compared to men enrolled in physics classes (Brewe et al., 2013). Forty percent of college STEM majors reported having difficulty in introductory STEM courses because of poor preparation in both physics content and scientific reasoning (Koenig, Schen, & Bao, 2012). Students who successfully complete a high school physics course are 2 times as likely to earn a 4-year STEM degree, yet only about 10% of American high school graduates ever take a physics course (Tyson, Lee, Borman, & Hanson, 2007). Nontraditional, non-lecture-based, minds-on, and hands-on enrolled high school physics classes show a dramatically increased participation rate than traditional lecture-based courses, and the number of graduates who intend to major in a STEM field doubles in these types of programs regardless of students' gender (Brewe et al., 2013; Koenig et al., 2012; Tyson et al., 2007).

Teaching method is a key factor in student learning of introductory physics in high school and, according to the NCES (2012), lecture-based instruction is ineffective. Traditional teacher-centered instruction (TI)in physics fails to help students replace their existing misconceptions with an accurate understanding of physical phenomena (Hestenes, Wells, & Swackhamer, 1992). White and Tesfaye (2010) discussed the ineffectiveness of lecture-based instruction in physics, yet the movement toward a less traditional, student-centered, guided inquiry form of learning has been slow. Jackson (2015) posited, "High school physics is the chief pathway to college STEM majors. The active learning of physics, such as Modeling Instruction, strengthens that pathway and also produces world-class scientific and mathematical literacy" (p. 1). The purpose of this study was to examine the effect of a nontraditional type of instruction called modeling instruction (MI) on freshman physics students' concept knowledge as measured by the Force Concept Inventory (FCI). The FCI is a 30-question test that researchers have used extensively to measure students mechanics concept understanding (Liang, Fulmer, Majerich, Clevenstine, & Howanski, 2012). The effectiveness of MI to increase FCI scores could be used as a central theme for developing an effective physics-chemistry-biology (PCB) curriculum model for the school.

The Local Problem

Schools need to find more effective ways to inspire and guide students on a STEM career path. This nation's future is directly associated with the ability of the schools to address this STEM workforce skills gap. The demand for STEM professionals continues to grow, and the supply of these skilled professionals is declining.

Locally, a rural high school science department has made some progressive changes to improve the science achievement, scientific literacy, and student interest in scientific career fields (school principal, personal communication, August 24, 2012). The most dramatic move involved the change from a traditional biology-chemistry-physics (BCP) course sequence to a PCB sequence (school counseling office, personal communication, May 13, 2013). With physics now a freshman level, concepts-based, foundational course, the school's science educators have been focusing on implementing effective instructional practice in Newtonian mechanics as the basis of an effective introductory course (school principal, personal communication, May 17, 2013). A large majority of beginning physics students enter the course with many experience-based misconceptions about basic Newtonian mechanics concepts (Hestenes, 1987).

The problem I investigated was the lack of success in current ninth grade high school physics instruction at the school in a rural district. Specifically, I researched the effectiveness of teaching students with MI as a possible solution to the current low achievement in ninth grade physics concept understanding. MI focuses on a student's ability to design an experiment to solve a problem in the same fashion that a professional scientist solves a problem (Jackson, Dukerich, & Hestenes, 2008). It guides a student through the process of collecting data, analyzing the data, drawing conclusions from the data, and building a model that can be used to help explain and defend the findings. The success of MI is directly related to the instructor's skill at guiding the modeling process. Although leaders in many schools in metropolitan areas have adopted MI with overall positive results, there is little support and research for MI in rural areas (White & Tesfaye, 2010). This study was designed to analyze MI effectiveness on student FCI scores in a rural setting.

Rationale

A 2003 Program for International Student Assessment (PISA) report showing the United States as below average in science literacy (NCES, 2012) led to a national call for science education reform and increased rigor in science and math education (Lederman & Bardeen, 2002). According to the National Science Teachers Association (NSTA; as cited in NCSES, 2012), since 1985 there has been a steady decline in the number of students pursuing degrees in STEM-related fields. As of 2013, the United States was

32nd in the world in producing graduates with STEM degrees (Robinson & Ochs, 2008; Rothwell, 2013). Fifteen out of 20 of the fastest-growing employment opportunities require STEM skills (Melguizo & Wolniak, 2012). The largest part of the problem is that while STEM careers are growing rapidly, as of 2011 fewer than 8% of American college graduates were awarded degrees in STEM subjects (BLS, 2011). More than 90% of all STEM professionals live in Asia (Rothwell, 2013; Terrell, 2007).

One of the primary goals of the National Science Foundation (NSF) over the last decade has been to increase science and math course-taking among high school students (NCSES, 2012). Some of the NSF directives are asking high schools to require more math and science credits for graduation, creating more rigorous standards for high school science courses, and encouraging students to take more of these courses (NCSES, 2012). The NACE (2014) has called for education reform in the realm of changing societies support for STEM education, exposing all students to STEM careers, integration of STEM subjects in every school, and funding special STEM education opportunities for teachers.

Evidence of the Problem at the Local Level

Students at a small, rural Arizona high school have demonstrated below-average to average levels of science achievement as measured by state and national standardized measures (school counseling office, personal communication, May 13, 2013). The school is located in a community population of fewer than 5,000 people (U.S. Census Bureau, 2012). The community is isolated by almost 200 miles of open land in all directions. The high school has a student population of approximately 425 students (school counseling office, personal communication, May 13, 2013). It is classified as a Title I school, with 54% of the student population qualifying for the free or reduced lunch (FRL) program (Arizona Department of Education [ADE], 2013). Only one high school exists in the district and the community.

Two standardized tests, the Arizona Instrument to Measure Standards (AIMS) and the American College Testing (ACT) science sections, were designed to measure student levels of scientific reasoning. Figure 1 illustrates percentage of students at the site passing AIMS Science section compared with the rest of the state of Arizona (ADE, 2013). Figure 2 shows mean ACT science scores at the site compared to state and national mean scores (school counseling office, personal communication, May 13, 2013).

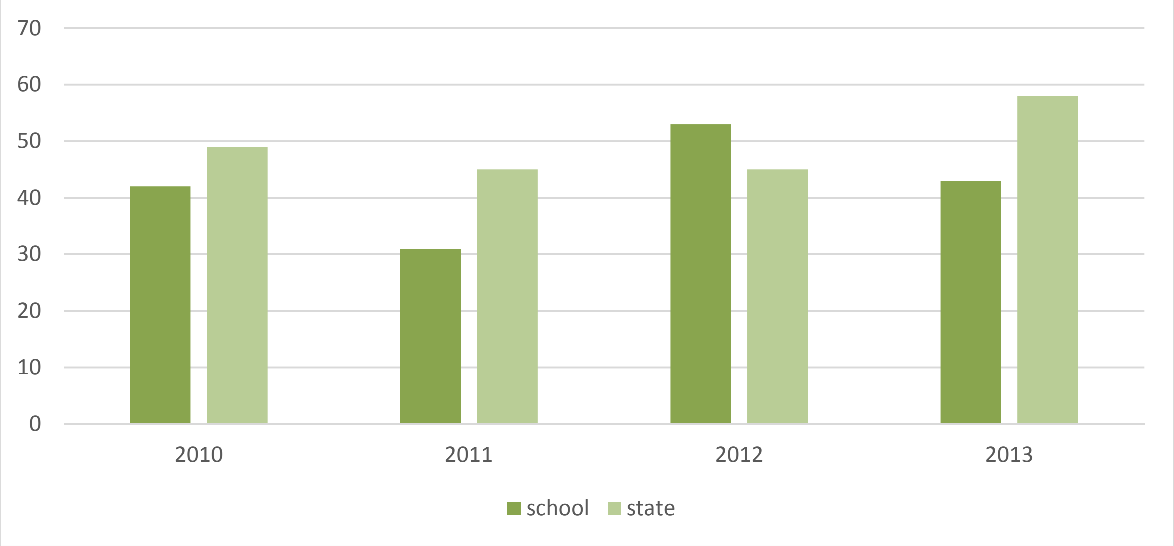

Figure 1. Percentage of students passing AIMS science by year.

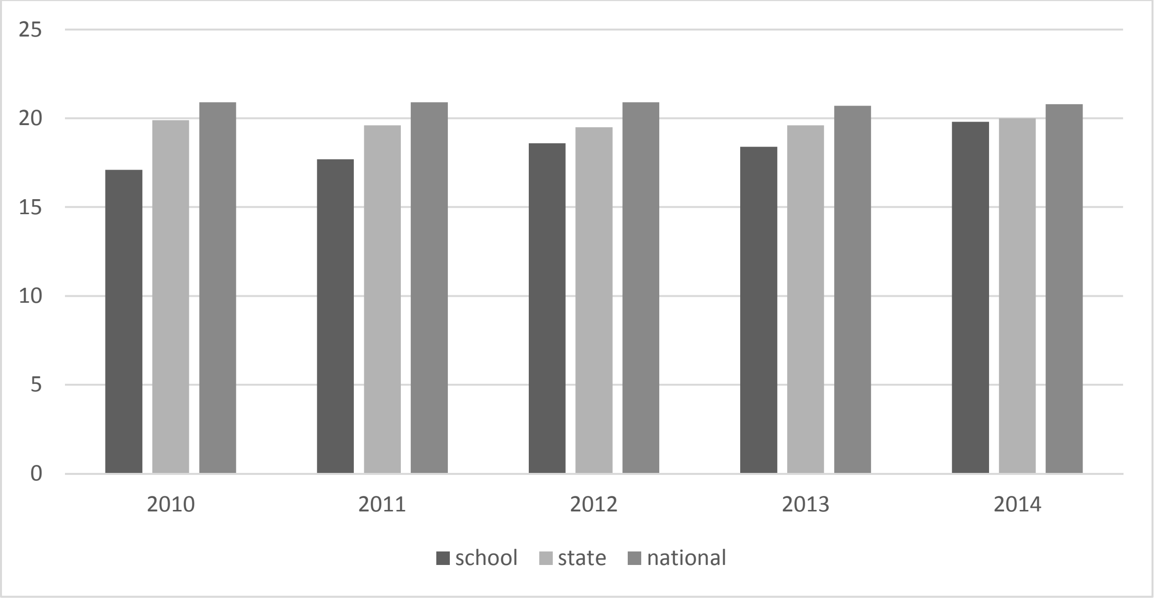

Figure 2. Mean ACT science scores by year.

Although average scores in the school on both measures showed some improvement over the past 3 years, they remained for the most part below the rest of the state on AIMS and state and national averages on ACT. School officials regularly cited student demographics as the major reason for this low achievement (school principal, personal communication, August 24, 2012). Low test scores in the school could be attributed to three classifications made by the NCSES (2012): (a) small, (b) rural, and (c) high poverty. Low upper-level science course credits earned, as well as low performance, particularly in the subject areas of math and science, have been attributed to all three of these classifications.

The science department staff has taken several curriculum-based steps to improve science education and science achievement for all of the school’s students. The requirement for graduation was increased from two to three science credits for the class of 2009 (school counseling office, personal communication, May 13, 2013). Students who had more science classes on their transcript also showed improved achievement in all subject areas, particularly in math and science (NCES, 2012). Progressively from 2009 to 2012, the course offerings were narrowed, removing broad science electives and focusing instead in-depth on biology, chemistry, and physics (school counseling office, personal communication, May 13, 2013). Students who experience in-depth learning in a science subject area show greater achievement in future scientific endeavors (Schwartz, Sadler, Sonnert, & Tai, 2009). Beginning with cohort class of 2016, all students were required to follow the sequence of physics-first, followed by chemistry, and then biology (school counseling office, personal communication, May 13, 2013). The field of biology has experienced the most dramatic changes of all the sciences. A strong foundation of chemistry is therefore essential for the study of modern biology (Lederman, 1998). For students to construct a strong conceptual understanding of the abstract world of the atom, they should have a concrete understanding of the basic laws of the physical world (Lederman, 1998, 2008; Liang et al., 2012). A high school science sequence of physics first, followed by chemistry, and concluding with molecular biology (PCB) guides students through the process of learning modern science in a way that naturally makes sense (Lederman, 1998). The department has received the full support of district administration and school board for all of their efforts, including the move to the PCB sequence (school principal, personal communication, August 24, 2012). All changes were based on research, state and national standards, and the recommendations of the NSF.

As noted earlier, despite the implementation of each of these NSF-recommended revisions to the school’s science curriculum, students in the school have still lagged behind state and national ACT and AIMS averages. Students completing freshman physics have demonstrated little in their understanding of mechanics concepts, as evidenced by FCI pre- and posttest averages. The FCI is a 30-item multiple-choice pre- and posttest designed to measure conceptual understanding of physics concepts (Halloun & Hestenes, 1985). The school's 81 freshman physics students showed a small gain of 9.5% following traditional instruction in mechanics (school counseling office, personal communication, May 20, 2013).

If the PCB sequencing is to be effective for improving the scientific literacy of all students, the students must leave first-year physics with a concrete understanding of Newtonian mechanics. Therefore, in this study I examined the effects of MI, which has led to significant gains in FCI scores and mechanics understanding among thousands of students and teachers (Hestenes et al., 1992). Students who demonstrate higher gains on the FCI have a stronger understanding of physical mechanics reasoning (Hestenes et al., 1992). Freshman physics students were taught mechanics using MI, with the hope it could increase their FCI gains. Greater gains on the FCI could lead to higher science averages on the AIMS, ACT, and science achievement overall. This, in turn, could lead to scientifically literate graduates prepared to successfully pursue a science, technology, engineering, or mathematics career field.

Schools that exist in rural areas show 6% lower proficiency scores on national science tests when compared with students in suburban schools (NCES, 2012). The small Arizona school is no exception to this trend. Only 10% of the school's students were considered college-ready by 2010 and 2011 ACT standards in science (school counseling office, personal communication, May 13, 2013). Students have been entering the school's freshman physics class with many misconceptions regarding basic Newtonian mechanics concepts and leaving the class to begin chemistry the following year, still holding on to these same misconceptions. The students' lack of mechanical concept knowledge has been reflected in their 2013 FCI posttest scores (school physics teacher, personal communication, June 6, 2013). Consequently, marginally effective physics learning by the school's freshmen could minimize effects of other changes to the science curriculum implemented to increase student achievement and interest in science. If this critical introductory physics class is to provide the foundation for the rest of their high school science education, its effectiveness must be measured and continually improved.

Evidence of the Problem From the Professional Literature

Research has supported the benefits of student-centered teaching strategies in introductory physics courses for adolescents ranging in age from high school freshman to college level (Campbell, Zhang, & Neilson, 2011; Hake, 1998; Halloun & Hestenes, 1985; Huffman, 2006; Tahir, 2010; Taslidere & Eryilmaz, 2009; Wells, Hestenes, & Swackhamer, 1995). Although these research-based pedagogies have a variety of titles, they have a few common aspects: (a) lessons are student-centered; (b) they promote evolving student explanations of phenomenon; (c) the classroom fosters active engagement between students, peers, and the instructor; and (d) they all emphasize the existence and importance of the many common misconceptions that students bring to the classroom (Jackson et al., 2008). While these models of effective physics teaching have shown positive student achievement results compared to traditional teacher-centered, lecture-demonstration-lab methods, the movement to student-centered instruction nationwide has been slow (White & Tesfaye, 2010). According to the American Institute of Physics, from 1990 to 2009 the percentage of schools moving from a traditional curriculum to an active conceptual approach has only grown by about 21% (White & Tesfaye, 2010).

This study was designed to benefit the school's freshman physics students by utilizing MI to improve their understanding of conceptual mechanics. MI guides students through the construction of physics-mechanics knowledge in much the same way that scientists practice (Hestenes, 1987). Students transition from the cognitive to the formal by forming new connections from experience and observation to their prior understanding of concepts (Inhelder & Piaget, 1958). Students develop models to describe a physical phenomenon and are required to defend all aspects of the model (Jackson et al., 2008). The modeling process engages students in finding conflicting explanations within their model and correcting them throughout the process (Jackson et al., 2008). This process helps students progress from simple-concrete knowledge to higher-level more abstract thinking while also developing the student's problem-solving ability (Jackson et al., 2008).

MI makes the construction and application of concept models of physical phenomena the focus of learning mechanics (Hestenes, 1987, 1997; Wells et al., 1995). Hestenes (1987) developed the modeling method of physics instruction at Arizona State University "to help students develop a more coherent, flexible and systematic understanding of physics" (p. 4). Hestenes designed MI to teach students to construct and apply conceptual models in mechanics (Jackson et al., 2008). Since the beginnings of MI, researchers have been collecting empirical data to support the pedagogy and to guide its evolution (Hestenes, 1992; Jackson et al., 2008). Fully implementing MI could help break down the many misconceptions in mechanics that the school's students bring with them to the classroom. By receiving help to better understand complex physics concepts at the start of their high school careers, students could experience success throughout all of their science education in high school and beyond, which could eventually lead to a career in the sciences.

Definition of Terms

Force Concept Inventory (FCI): A multiple-choice mechanics test that makes the student choose between the correct concept and a set of common misconceptions (Wells, et al., 1995). The FCI has been used extensively for diagnostics and as an instructional evaluation tool.

Hake Gain on the FCI: Hake (1998) utilized the following FCI calculations to determine students understanding of physics concepts. Student gain (g) and averaged normalized gain (G) calculations:

$$g = (\%\, posttest\ score - \%\, pretest\ score)\ \div (100 - \%\, pretest\ score)$$

$$G = (\%\, posttest\ class\ average - \%\, pretest\ class\ average)$$

$$\div\, (100 - \%\, pretest\ class\ average)$$

(Hake, 1998)

Hake's class gain: Low gain is less than 0.3, moderate gain is between 0.3 and 0.7, and high gain is greater than 0.7 (Hake, 1998).

Mechanics: The study of the motion of objects as outlined by laws put forth formally by Sir Isaac Newton (Hewitt, 1987).

Misconceptions: Inaccurate notions about physical phenomena carried into a beginning physics course. MI conceptions are difficult for students to replace even after they have been instructed to the contrary (Halloun & Hestenes, 1985).

Modeling instruction (MI): MI makes the construction and application of concept models of physical phenomena the focus of learning mechanics (Hestenes, 1987, 1997; Wells et al., 1995). MI focuses students on constructing and applying conceptual models in mechanics (Jackson et al., 2008). MI has four fundamentals for students: (a) designing and conducting experiments in small groups, (b) writing and sketching out explanations of what happened and why, (c) defending their model through peer presentation, and (d) critically discussing the models developed by their peers (Jackson et al., 2008).

Physics-first: A high school science sequence of physics first, followed by chemistry, and concluding with molecular biology (PCB) guides students through the process of learning modern science in a way that naturally makes sense (Lederman, 1998).

Traditional instruction (TI): Teacher-centered, lecture-demonstration-follow-directions type instructional methods that use the passive learning of students from an instructor (Basu, 2008; Campbell, et al., 2011; Geier, et al., 2008; Halloun & Hestenes, 1985; Lawrenz, Wood, Kirchhoff, Kim, & Eisenkraft, 2009; MacMillan, 2009; Schwartz et al., 2009).

Significance of the Study

Finding and using effective instructional strategies in physics will help students remove misconceptions, replacing existing inaccurate concept knowledge with correct understanding of these concepts (Wells et al., 1995). Improving science and mathematics instruction is the most immediate way to increase student achievement in STEM subjects (Dye, Cheatham, Rowell, Barlow, & Carlton, 2013). MI has been effective in a wide variety of introductory physics educational settings, from college level to high school freshmen (Jackson et al., 2008). Until recently, few researchers had examined the effects of MI within the PCB sequence. While the PCB sequence offers promise for addressing the national, state, and local need for improved science achievement, it is a broad, all-encompassing approach (Lederman, 2008).

Science teaching in itself is the most immediate way to improve scientific literacy and achievement individually and locally (Jackson et al., 2008). In studying types of effective instruction, a school can use classroom instruction that provides students with immediate success. Classroom research addressing instruction in physics at the high school level might help to provide future scientists and engineers to a professional population that would benefit from a larger, more balanced representation. If MI shows significant positive results locally, a study could contribute to positive social change by improving all science instruction at the site as well as other locations that have the same need to improve achievement in science for their typically underrepresented populations. Classroom success for rural students, and for female students, in particular, could help stimulate those students toward pursuing a career in STEM.

Research Questions and Hypotheses

Data from the FCI had been collected and used at the site to help provide physics teachers with a means to measure the effectiveness of their teaching. The FCI data are also used by the school's administration as part of the bi-yearly teacher evaluation process. During the first year the administration implemented freshman physics, a traditional teaching approach was the primary method of instruction. The FCI pre- and posttest was administered to give stakeholders a measurement of student's concept knowledge gains following instruction. During summer break, the school's physics teacher participated in an intensive 3-week MI workshop for teaching mechanics at Arizona State University. The following academic year, the teacher used MI as the primary mode of instruction, and FCI data were collected and analyzed. To understand the effects of MI on the school's freshman physics students and their understanding of physics concepts, I addressed three guiding research questions:

RQ1: Is there a difference in FCI gain scores of ninth grade physics students who were taught using MI compared to students who were taught using TI?

The hypotheses to be tested were the null (H_0), and the alternative (H_a).

$H_0$1: There is no statistically significant difference in FCI gain scores of ninth grade physics students who were taught using MI compared to students who were taught using TI.

H_a1: There is a statistically significant difference in FCI gain scores of ninth grade physics students who were taught using MI compared to students who were taught using TI.

The independent variable was the instructional type; the dependent variable was the gain scores on the FCI test.

RQ2: Is there a difference in FCI gain scores between ninth grade male and female students who were taught using MI?

$H_0$2: There is no statistically significant difference in FCI gain scores between ninth grade male and female students who were taught using MI.

H_a2: There is a statistically significant difference in FCI gain scores between ninth grade male and female students who were taught using MI.

RQ3: Is there a difference in FCI gain scores between ninth grade male and female students who were taught using TI?

$H_0$3: There is no statistically significant difference in FCI gain scores between ninth grade male and female students who were taught using TI.

H_a3: There is a statistically significant difference in FCI gain scores between ninth grade male and female students who were taught using TI.

I expected that the answers to the research questions would provide greater support for the progress of science education from a traditional teacher-centered environment to one that is student-centered and overall more effective for learning. Recent research has shown that active instruction such as MI has a positive effect on students' understanding of physics concepts. Dye et al. (2013) and Liang et al. (2012) analyzed data from two independent movements in physics education in two large-scale, peer-reviewed studies on MI within the PCB sequence. Current and past research has shown positive support for both MI and PCB. The populations selected for previous research are almost exclusively urban and suburban students, who represent the largest part of the nation’s students. Approximately one quarter of all public school students in the United States are enrolled in rural schools (NCES, 2012). Twenty-five percent is a large gap in the population to leave out of the research pool; thus, I undertook this study of the effects of MI within the PCB sequence in a rural setting to help to close that gap. Answers to the research questions were expected to provide support for continuing progress toward a MI curriculum at the local site and other similar sites. Such improvements could lead to positive social change as these rural students experiencing MI will be adequately prepared to pursue a career in the STEM professions.

Review of the Literature

The results of numerous studies have supported the need for schools to reduce the amount of traditional instruction in introductory physics. Its ineffectiveness was brought to light by Halloun and Hestenes (1985), when data from MI research led them to conclude two things:

> (a) Common sense beliefs about motion are generally incompatible with Newtonian theory. Consequently, there is a tendency for students to systematically misinterpret material in introductory physics courses, and (b) common sense beliefs are very stable, and conventional physics instruction does little to change them. (p. 1)

In the following pages I will review the current literature, grounded in Piaget’s (1950) theory of cognitive development and connecting formal thought to physics education, on the underrepresentation of females in physics and MI. The review concludes with literature on some of the gaps in MI research and how this study addressed those gaps. The research suggested that physics instruction can be effective in increasing students' concept knowledge when it is experientially constructed, student-centered, involves student-peer-teacher discourse, and makes physical concepts relevant (Brewe et al., 2013; Campbell et al., 2011; Geier et al., 2008; Jackson et al., 2008; White & Tesfaye, 2010;).

Piaget's Theory of Cognitive Development

The process by which humans construct knowledge and understanding of their world has been analyzed and debated for over 100 years (Goodman & Etkina, 2008). The theory that knowledge is constructed by individuals through their experiences was deemed as fundamental by most of the world (Piaget, 1950). Piaget's theory of cognitive development influenced nearly every educational practice (Kretchmar, 2008). Piaget (1950) used the term *viable* to describe knowledge or action that is useful to solve or meet a particular objective. This viability is the knowledge action that distinguishes formal thought from the more basic concrete thought (Inhelder & Piaget, 1958). Learners naturally progress from concrete cognitive processes to more abstract formal cognitive processes during adolescence (Inhelder & Piaget, 1958). Piaget (1950) determined that this transition can be positively impacted when learners are given authentic scientific problems to work out. Scientific knowledge is built and expanded through the translation of prior knowledge to new experiences (Tahir, 2010). Experiences should be given to help students connect prior knowledge to the new, with the goal of solving problems at the forefront (Tahir, 2010).

Inhelder and Piaget (1958) conducted several studies with adolescents, providing simple physical phenomenon for these students to investigate. The results from these experiments showed a clear change from the basic concrete cognitive thinking in pre-adolescents to a higher more abstract form of reasoning (Inhelder & Piaget, 1958). When comparing preadolescents to adolescents in their thought approach to solving problems through experimentation, adolescents enter into a formal operational stage (Inhelder & Piaget, 1958). Ginsburg and Opper (1988) asserted, “The adolescent performs well at three aspects of the problem: (1) he *[sic]* plans the tests adequately, or designs the experiment properly, (2) he observes the results accurately, (3) and he draws the proper logical conclusions from the observations” (p. 183).

Students during adolescence are naturally transitioning from the concrete to the formal (Stefani & Tsaparlis, 2008). A pedagogy for teaching high school science courses that follows this same learning sequence leads to improved student learning. Scientific understanding naturally follows the process of constructing explanations of phenomena through experience, discussion, model development and evolution, and, finally, application of knowledge to a new scenario (Tahir, 2010).

The pinnacle function of Piaget’s formal thought is problem solving (Ginsburg & Opper, 1988), which involves the analyzing data, manipulating variables, and drawing conclusions that can be applied to other situations (Ginsburg & Opper, 1988). Researchers have shown that transitioning from concrete to formal understanding in science is as much a result of instructional technique as it is a result of maturity (Lawson & Wollman, 1976; Stefani & Tsaparlis, 2008; Tahir, 2010; Walker, Sampson, Grooms, Anderson, & Zimmerman, 2012). Inhelder and Piaget (1958) concluded, “A particular social environment remains indispensable for the realization of these possibilities. It follows that their realization can be accelerated or retarded as a function of cultural and educational conditions” (p. 237). In other words, age and maturation paralleled by specifically designed instruction in science can directly improve the development of problem solving ability in students.

Formal Thought Approaches to Physics Education

Every student entering a beginning physics class has a set of beliefs about physical phenomena based on his or her personal thoughts and experiences (Halloun & Hestenes, 1985). Many of these common beliefs that students bring with them conflict with the basics of natural physical mechanics as described by Sir Isaac Newton (Hamza & Wickman, 2007; MacMillan, 2009; Ogunleye & Babajide, 2011; Sherin, Krakowski, & Lee, 2012; Soormro, Qaisrani, Rawat, & Mughal, 2010; Taslidere & Eryilmaz, 2009). Most students tend to incorrectly interpret physics instruction holding onto their misconceptions and even resisting their replacement (Campbell et al., 2011; Hamza & Wickman, 2007; MacMillan, 2009; Ogunleye & Babajide, 2011; Soormro et al., 2010; Taslidere & Eryilmaz, 2009). Typical first-year physics instruction does little to correct this problem, and students leave class with little or no evidence of a better understanding of Newtonian mechanics (Basu, 2008; Campbell et al., 2011; Geier et al., 2008; Halloun & Hestenes, 1985; Lawrenz et al., 2009; MacMillan, 2009; Schwartz et al., 2009).

To study the effects of instructional technique on student concept knowledge in physics, Hake (1998) collected student pre- and posttest FCI data from physics teachers at the high school and college levels. Hake categorized the type of instruction into two main categories, traditional instruction (TI) and interactive engagement (IE). TI instruction consisted of teacher-centered lecture, lab, demonstration, and algorithmic problem solving; IE instruction involved hands-on, peer discussion that was activity-based and student-centered, with immediate feedback from the instructor and peers (Nieminen, Savinainen, & Viiri, 2012). Data were collected from more than 6,000 beginning physics students (Nieminen et al., 2012). All of the more than 2,000 traditionally taught students yielded an FCI gain below 30%, while the IE-instructed students yielded gains in the 30% to 70% range (Hake, 1998). Students taught using IE have greater success replacing their original misconceptions with accurate mechanics concept knowledge (Naron, 2011).

Geier et al. (2008) examined poor science achievement test scores following traditional physics instruction. The researchers evaluated a curriculum program called "Active Physics." In the 3-year study within the Detroit public school system, Geier et al. compared standardized test results between control groups receiving traditional instruction and treatment groups receiving active physics instruction. Thirty-seven teachers in 18 schools and approximately 5,000 students participated in the prescribed curriculum (Geier et al., 2008). Each year in the study involved a gradual scale-up of the curriculum. The Michigan statewide high-stakes test was used as the measure of achievement in. The data were separated into cohort subgroups involving a pooled comparison of students who participated in the curriculum with those who did not. Total raw science scores were examined along with raw scores in each of the five content and process level areas. Results showed that students in treatment groups significantly outperformed their control group peers not only in mean science scores but in all individual categories of science (Geier et al., 2008). Detroit students who were taught physics with a traditional method did not improve their concept knowledge.

MacMillan (2009) studied the conceptual problems that students have in understanding momentum and kinetic energy and the treatment that 44 different physical science textbooks use to address these problems. According to MacMillan, students often leave their introductory physics courses with competing explanations of momentum. Students benefit from explaining physical phenomena qualitatively, in writing, as opposed to mathematical problem solving (MacMillan, 2009). Students who were able to solve calculations could not answer general comprehension problems (MacMillan, 2009). MacMillan categorized the approach of these popular United Kingdom textbooks in the chosen areas. Most of the textbooks began with a definition or a formula for momentum and offered no real-world applications, which are a key part of bridging experience with new knowledge (MacMillan, 2009). Only eight out of 29 advanced books show any realistic situations (MacMillan, 2009). Thus, MacMillan concluded that rote learning of physics concepts does little for the development of student concept knowledge and has adverse effects on their engagement with physics. The author argued that students should be encouraged to describe and test more deeply the phenomenon and technology that they see every day, and number crunching should be minimized and simulations should be created to resolve conflicting explanations.

In an ethnographic study, Basu (2008) addressed the effects of traditional physics instruction on low-income minority students, who historically had shown low achievement in physics and math following traditional instruction. After observing and interviewing five ninth grade physics students, Basu concluded that when students develop intellectual identity through active engagement in physics, they are likely to generate a connection and deep understanding to the conceptual components of physics (Basu, 2008). Student voice puts the student directly involved in the relevance of science to their lives and culture and leads to higher conceptual understanding of physics (Basu, 2008).

Female Underrepresentation in Physics

In scientific career fields, women dominate the life and health sciences and men dominate physics and engineering (Quinn & Lyons, 2011). Men have continued to out-populate women in entry-level college math and physics courses; the difference is magnified in engineering and computer science (NCSES, 2012). Quinn and Lyons (2011) analyzed data from 3,800 sophomore high school student surveys in an attempt to identify impediments to girls entering STEM career fields. The researchers sought to better understand students' (a) self-rated science ability, (b) enjoyment of high school science, and (c) perception of job security in science fields (Quinn & Lyons, 2011). The primary contributing factor in influencing career choices in science after high school is student self-concept regarding science aptitude (Quinn & Lyons, 2011). All students, particularly girls, are more apt to choose a STEM career if they have a high self-concept regarding STEM after high school. The primary contributing factor in influencing career choices in science after high school is student self-concept regarding science aptitude (Quinn & Lyons, 2011).

Simpkins, Davis-Kean, and Eccles (2006) showed that boys demonstrate a higher self-concept than girls regarding science ability. This lower self-concept by girls is not supported by lower academic performance in science at the high school level, because girls tend to get better grades in science and achieve comparable results on standardized tests in science when compared to boys (Halpern et al., 2007). Anything that can be done to boost girls' self-confidence in STEM begins in the classroom (Mosatche, Matloff-Nieves, Kekelis, & Lawner, 2013). Math and science must be connected to real life and should be hands-on and relevant to both boys and girls (Mosatche et al., 2013). Many of the suggested interventions are merely characteristics of good teaching (Brotman & Moore, 2008). To contribute to the overall effort for social justice and increasing female involvement in scientific careers and endeavors, science educators and education researchers can use the classroom to begin to counteract centuries of socialization (Murphy & Whitelegg, 2006). Inequality can be reduced in science classrooms by adopting cooperative learning strategies, facilitating higher-order thinking, choosing depth over breadth, and using authentic inquiry learning that highlights socio-scientific aspects of STEM (Eccles, 2005). MI in high school physics could help to create an avenue to rectify this issue.

MI

Hestenes (1987), who developed a modeling theory of physics instruction, described how a teacher could guide students through the construction of physics mechanics knowledge in much the same way that scientists practice in the field. MI makes the construction and application of concept models of physical phenomena the focus of learning mechanics (Hestenes, 1987, 1997; Wells et al., 1995). Students who have studied physics at any grade level have a great deal of difficulty describing in detail even the most basic Newtonian concepts (Jackson, 2015; Naron, 2011). They enter physics classes with many deeply imbedded misconceptions and continue to hold onto the same inaccurate notions even after completing formal instruction in physics (Wells et al., 1995). Halloun and Hestenes (1985) argued, “The primary objective of introductory physics instruction should be to facilitate a transformation of the student’s mode of thinking from his initial common sense knowledge state to the final Newtonian state of a physicist” (p. 11). MI systematically guides students through observation, description, explanation, and defense of their model until the progression becomes a natural routine (Jackson et al., 2008).

Dye et al. (2013) studied how MI, when used within a PCB sequence, affected student achievement as measured by ACT scores. Using comparative data analysis from 600 students sorted into cohorts, the researchers found that student treatment groups who were taught using MI in freshman physics showed significantly higher science achievement (Dye et al., 2013). The study, the first to collect data on MI within the PCB sequence, was implemented to gather data that could help address the national concern of low science achievement (Dye et al., 2013).

MI meets all of the criteria for a comprehensive approach to effective science learning. Parallel to the experiential learning studied by Inhelder and Piaget (1958), the

MI basics involve students (a) designing and conducting experiments in small groups, (b) writing and sketching out explanations of what happened and why, (c) defending their model through peer presentation, and (d) critically discussing the models developed by their peers (Jackson et al., 2008). The process leads to students habitually thinking critically about their own explanations as well as other alternative explanations.

Liang et al. (2012) studied the effects of MI specifically on 301 high school freshmen and five teachers in a physics-first setting. MI in the freshman classroom was compared with TI in the junior-senior classroom (Liang et al., 2012). The FCI was used as the instrument to measure student conceptual understanding of mechanics in physics. The researchers found that students who were taught using the MI significantly outperformed their older traditionally taught peers in physics concept knowledge (Liang et al., 2012). Furthermore, follow-up data from the district showed that student enrollment in advanced science classes dramatically increased over time for both boys and girls as the MI taught freshmen became upperclassmen (Liang et al., 2012).

Other findings from this study show the importance of the teacher’s ability to guide student discourse throughout the modeling process (Liang et al., 2012). The stronger the teacher’s training in the understanding of common student misconceptions, the greater is his or her ability to guide students through critical model development and, in turn strengthen, their understanding of concepts (Liang et al., 2012). Students show higher achievement in physics concept knowledge as teachers become more proficient in guiding MI (Jackson et al., 2008). A training program for teachers at Arizona State University has trained nearly 3,000 teachers across the country and abroad how to implement MI (Jackson et al., 2008). Data on nearly 20,000 students have been collected from MI-taught physics students driving the evolution and expansion of the program (Jackson et al., 2008).

Gaps in Prior MI Research

Research in MI for introductory physics has provided data to support the continued use and development of the instructional method. Most of the body of research has focused on urban and suburban high school students rather the effects of MI on several typically underrepresented groups, including female students. Only Liang et al. (2012) have examined MI within the PCB sequence, although it was limited to two mid-Atlantic suburban high schools and did not address the effects of MI on female students compared to male students (Liang et al., 2012). A study of rural students that also focuses on girls is still needed to better understand the effectiveness of MI on this typically underrepresented population. The addition of research on MI to include greater diversity of sampling would strengthen the generalizability of the data and include rural student data (Lodico, Spaulding, & Voegtle, 2010).

Implications

The effectiveness of high school physics instruction is dependent in large part on teachers and their pedagogical mastery and teaching methodology (Wells et al., 1995). My research was intended to show whether using MI to instruct freshman physics students would result in improvement of their conceptual understanding of physics as measured by the FCI. The school’s physics teacher participated in an intensive 3-week summer modeling workshop at Arizona State University. The course is designed to introduce the modeling method for mechanics and help the participants gain the skills needed to implement it (Hestenes, Megowan-Romanowicz, Popp, Jackson, & Culbertson, 2011). The MI was implemented in all freshman physics classes for the 2013-2014 school year. FCI pre- and posttest scores were compared to gain a better understanding of the effectiveness of MI on rural freshman physics students.

Data from this research could be used to support the development of a formal thought-based, student-centered, active-learning curriculum to be implemented across the PCB sequence. Model development by students was at the center of the curriculum. By design, if results from this study had shown freshmen had a strong understanding of physics, a larger project would have been developed to gradually increase the use of MI and reduce the amount of traditional instruction in physics, chemistry, and eventually biology at the site. If students were to begin their sophomore year with an understanding of conceptual model building in mechanics, they could use the same technique to guide their understanding of the invisible and abstract world of chemistry. A coherent PCB curriculum would be developed to guide students through the construction of scientific concept knowledge. Students at the site might be developed into genuine problem-solvers in science. The learning experience could help increase student achievement in science overall in high school and lead to scientifically literate graduates who choose to pursue STEM careers.

Summary

Freshman physics students at the rural Arizona school fit the underrepresented criteria and had the greatest potential for benefiting from MI. Training the school's physics teacher in MI could begin to provide the knowledge and support needed for the successful implementation of a model-based curriculum at the school. MI is a research-based pedagogy that received the endorsement of NSF in 1989 and the recommendation of the National Science Education Standards, National Council of Teachers of Mathematics Standards, and the Benchmarks for Science Literacy (Jackson et al., 2008). MI taught students regularly show concept knowledge gains double to that of traditionally taught students, and MI particularly shows achievement success in underrepresented students who typically do not succeed in physics (Jackson et al., 2008). Data from a study at the local site could provide support for MI. It could help students at the school improve their achievement in science for the long term and guide them toward scientific careers to meet their need and the needs of the world as a whole.

Section 2: The Methodology

Introduction

The purpose of this study was to examine how implementing MI would affect FCI scores for ninth grade students enrolled in freshman physics at a rural high school. I tested the hypothesis that there would be a significant difference in FCI gain scores between freshman physics students from graduating cohort 2017 who were taught using MI and freshman physics students from graduating cohort 2016 who were taught using TI. I also compared female to male students from both cohorts in terms of their gains in physics concept knowledge.

Research Design and Approach

In this quantitative, quasi-experimental study, the FCI pre- and postinstrument was used to assess students' knowledge of Newtonian physics concepts. This design was suitable because I sought to assess the impact of a treatment variable on an outcome (Creswell, 2012). A quasi-experimental study that included a control group with parallel demographics was used to determine the impact of an intervention (Creswell, 2012). This design was chosen primarily because of the educational setting, where it was not feasible to use random sampling (Lodico et al., 2010). The FCI is a summative evaluation that assesses the performance of the group as well as individual students following instruction (Halloun & Hestenes, 1985).

Setting and Sample

The participants in this study all attend a small, rural Arizona high school with an enrollment of 398 students (school counseling office, personal communication, May 13, 2013). A nonprobability sample was available and convenient, and it represented the specific elements that I sought to address (Creswell, 2012). The populations from which the data were collected included two freshman class cohorts designated by their projected graduating year. The 2016 cohort class, which will graduate in May 2016, was taught physics as freshmen using a TI approach. This cohort included 81 students and the entire cohort represented the control group. The 2017 cohort class will graduate in May 2017 and was taught physics using MI. The entire population of 103 students represented the treatment group. Nonrandom census sampling was used because I was trying to learn about a specific population in my own district (Lodico et al., 2010).

The site has a small overall population, and a census sample gives the maximum number of participants for a local study (Creswell, 2012). All freshmen regular education students have been required to take physics for the past two school years (school counseling office, personal communication, May 13, 2013). The 2016 and 2017 cohort classes represented the target population of the study, and the population as a whole provided the largest amount of data (Lodico et al., 2010). With a maximum standard deviation of 3.64 (school physics teacher, personal communication, August 24, 2014), and a one-tailed alpha level of .05, a sample of 81 would allow a true FCI difference of 1.5 or more to be detected with a +power level of .80 (Lenth, 2006).

Teaching Approach

The 2016 graduating cohort freshman class was taught physics using TI teaching methods that were guided by the Arizona State Standards for teaching science. TI followed the basic model of lecture, discussion, and pre-established lab experiment or demonstration, followed by explanations by the instructor and mathematical problem solving by the students. The instruction was based on the contents of Hewitt's (1987) text *Conceptual Physics: A High School Program*. The course followed a widely used conceptual mechanics format: (a) motion, (b) Newton's first law, (c) Newton's second law, (d) Newton's third law, (e) vectors, (f) momentum, (g) energy, (h) gravity, and concluding with (i) circular motion (Hewitt, 1987). Traditional instruction evaluation methods were employed and included end-of-chapter tests, written lab reports, student projects, and the FCI administered as a pre- and posttest. Students received instruction in mechanics for 55 minutes per day for 1 school year.

The 2017 cohort freshman class was taught physics using MI. Prior to the school year, the school physics teacher participated in an intensive 3-week MI course at Arizona State University. Successful completion of the course qualified the teacher as a "novice modeler," and the MI curriculum was implemented by the teacher following approval by the site administrator. The primary difference between an MI classroom and TI classroom is that the role of the teacher changes. The TI teacher served as the head of learning and the transfer of knowledge to the student. The MI teacher became the designer of experimental environments, problems, and activities. The teacher did not lecture but became a critical listener of students and their scientific arguments. The teacher instructed the students in the stages of model development: (a) description, (b) formulation, (c) ramifications, and (d) validation. The model development process was used repeatedly for the entire year as the method for students to understand physics concepts in mechanics.

Unlike a traditional curriculum based on a long series of Newtonian concepts taught in isolation, the entire MI curriculum is based on just a handful of physical systems. The modeling systems are constant velocity, constant acceleration, free particle interaction, constant force, energy, and momentum. Students were guided to develop their own model of a phenomenon they observed through a simple experiment. The central component of model development is students using a whiteboard to describe their models. Students in small groups shared their thoughts and collaboratively generated verbal, diagrammatic, graphical, and algebraic representations of a physical system. The groups drew out symbolic representations on a small, 2-sq ft whiteboard, and each group presented the model to the class. The groups then defended, refuted, and collaborated on their results and created ways to apply their model to a variety of situations. As students began to model effectively, different types of problems were given to the groups in a variety of formats. Ultimately, students learned physics the same way that scientists make real discoveries. The school had only one physics teacher, who delivered all of the instruction. Students received MI in mechanics for the same 55 minutes per day for one school year as the TI group.

Instrumentation and Materials

Student concept knowledge for mechanics was assessed using the FCI as a pretest for both cohorts. The FCI pretest was followed by a school year of instruction. Cohort 2016, the control group, received TI. Cohort 2017 received a treatment of MI in mechanics from the same instructor. Both the control and treatment groups were assessed at the end of the school year using the FCI as a posttest. Growth scores between the preand posttest data from the FCI were calculated. The effectiveness of a treatment group compared to a control group was assessed with a *t* test. Cross-sectional analysis of data from the FCI for cohort 2016 and 2017 was collected ex post facto following proper approval and permissions. The FCI requires students to make a “forced choice between Newtonian concepts and common sense alternatives” (Hestenes et al., 1992, p. 142). The FCI is a password-protected, 30-item, multiple-choice assessment that brings with it a high measure of validity and reliability (Halloun & Hestenes, 1985; Hake, 1998).

The validity of the 1992 version of the FCI has been well established beginning with its earlier 1985 version, known as the Mechanics Diagnostic Test (Halloun & Hestenes, 1985). The test developers built the FCI with validity and reliability as a central focus (Halloun & Hestenes, 1985; Nieminen et al., 2012). The 1995 version used in this study consisted of 30 multiple-choice items covering basic Newtonian concepts (Nieminen et al., 2012). Scores range from 0 to 30 according to the number of correct answers. Each test item has five alternative answers; one is correct and four are common misunderstandings and incorrect (Nieminen et al., 2012). The FCI is easy to administer and for students to take (Nieminen et al., 2012). The FCI questions do not require any calculation but a basic working knowledge of physics mechanics concepts (Lasry, Rosenfield, Dedic, Dahan, & Reshef, 2011). Data from the FCI are collected without researcher bias, and the results are numerical (Halloun & Hestenes, 1985; Nieminen et al., 2012). Researchers determined the unifying theme of force as an essential domain for the demonstration of mechanics understanding, and the FCI has repeatedly been used to measure this ensuring the tests validity (Halloun & Hestenes, 1985; Jackson et al., 2008; Liang et al., 2012; Nieminen et al., 2012; Lasry et al., 2011).

The initial reliability of the FCI was established by comparing distribution scores of different groups independently and through interviews with participants using their explanations for correct and incorrect answer choices (Halloun & Hestenes, 1985). Lasry et al. (2011) studied the FCI using a variety of reliability measures. Internal consistency reliability correlates half of an instrument to another half of the same instrument in a variety of ways (Lodico et al., 2010). The researchers used the Kuder and Richardson (KR20) reliability coefficient to measure mean correlations between every available half of the FCI (Lasry et al., 2011). The KR20 range from 0 to 1 determines that a mimimum coefficient level of .7 is the baseline for internal consistancy. The FCI was determined to have a KR20 coefficient of .9 (Lasry et al., 2011).

Equivilant form reliability measures the same sample group's scores on two or more measures of the same skill or construct to determine a correlation (Creswell, 2012). Thousands of cases comparing the FCI to other Newtonian concepts diagnostic tests found a correlation of .78, which is considered reasonably high (Lasry et al., 2011). Lasry et al. (2011) determined a test-retest correlation of .84, where .8 is considered stable. Huffman (2006) criticized the FCI for its ability to measure a single construct; however, the test writers responded immediately, criticizing the Huffman and Hellers data analysis (Halloun & Hestenes, 1985). While no measure is perfect in every way, the FCI has a long record of strong validity and reliability tests (Nieminen et al., 2012). The FCI is one of the most used instruments by physics educators and researchers to measure mechanics understanding of students worldwide (Nieminen et al., 2012).

Data Collection and Analysis

I collected data for this study ex post facto from the school's counseling office. The FCI pre- and posttest raw scores were gathered from the 2016 cohort and the 2017 cohort. Student identification was replaced with a generalized number by a site administrator in the counseling office, and each student's set of scores was marked to indicate the student's gender. The FCI was administered by the school's physics teacher beginning and followed a year of mechanics instruction. The 2016 cohort received TI, and the 2017 cohort received MI. The same teacher administered the test and instruction for both cohorts and the scores were submitted to the school's administration at year's end as part of the regular annual teaching evaluation measure. Archival data from the FCI were analyzed to answer the first research question (RQ1): Is there a difference in FCI gain scores of ninth grade physics students who were taught using MI compared to students who were taught using TI?

Data were analyzed within each cohort using three methods: (a) repeated measures *t* test, (b) the Hake gain method, and (c) between cohorts with an analysis of variance (ANOVA). Summarized below are the means by which the null hypothesis was tested. To compare gains of the two groups, a repeated measures *t* test was calculated for individual students and for whole cohorts to analyze the effectiveness of the instruction. A *t* score in the critical region would show a significant increase in physics concept knowledge (Halloun & Hestenes, 1985; Hake, 1998; Naron, 2011). Hake gains were calculated for both TI and MI cohorts and categorized as low, moderate, or high level of understanding of physics concepts in mechanics (Hake, 1998). A Hake gain is considered moderate if it falls between 30% and 70% for the class (Hake, 1998). Individual student data (g) and class average data (G) were analyzed with the Hake gain equations:

$$g = (\%\text{ posttest score} - \%\text{ pretest score}) \div (100 - \%\text{ pretest score})$$

$$G = (\%\text{ posttest class mean} - \%\text{ pretest class mean}) \div (100 - \%\text{ pretest class mean})$$

(Hake, 1998).

A *t* test and Hake gain (G) were calculated for male and female students from the treatment group and control group separately. Data from the two gender groups were compared and analyzed for significance. A two-tailed ANOVA was used to compare gains by gender and teaching method to see if there was a significant difference between teaching method and FCI gains for girls compared to boys.

Assumptions, Limitations, Scope, and Delimitations

I assumed there would be some degree of homogeneity between the control and treatment groups. The convenience, nonprobability, nonrandom census sample limited the ability of the research to be generalizable to all freshman physics students; however, significant results might have raised a flag for other schools with similar demographics. The control and treatment sample had the specific elements that were the focus of the study. The study was limited by my inability to control for some extraneous variables, such as the instructor’s additional year of teaching experience and maturity, as well as changes in the school and school population overall. The sample did not provide data for generalization; however, complete population access would provide ample data and may be robust for the site, the district, and schools with similar population demographics. The independent variables in the study were the MI and TI methods of teaching, and the dependent variable was student's gain scores on the FCI.

Protection of Research Participants

Data were analyzed ex post facto, and student information was de-identified to protect the personal identity of all participants. I collected all data and kept the information private at all times during analysis and otherwise locked in an unmarked file. I had no contact with the participants in terms of the research process. I received permission from the school, district and Walden University (IRB approval number 11-05-14-0198891) prior to any data retrieval. A letter of consent from the principal at the site can be found in Appendix A. Parental consent and student assent were not needed, because FCI testing is a normal part of the educational procedure. I gathered and analyzed all data after participants completed the course, and, to protect the participants' identify, no personal information other than students' gender and numerical scores were collected. I successfully completed the Protecting Human Research Participants training course with the National Institute of Health on February 25, 2012.

Data Analysis Results

The participants in this study were given the FCI as a pretest prior to the start of freshman conceptual physics instruction. The FCI was then given as a posttest immediately following 10 months of physics instruction. The 81 students from cohort 2016 were taught physics primarily using traditional instruction and represented the control group in the study. One hundred and three regular education students, 88% of the school’s entire freshman cohort class, were taught using MI and represent the treatment group. Both the control and treatment groups comprised freshman physics students and were taught by the same teacher under the same basic conditions. All regular education students at the site must enroll in freshman physics as a requirement for graduation. Data were analyzed to compare the FCI gain scores of treatment and control groups and to compare the FCI gain scores of females to males using two methods. First, raw score mean gains for both groups were calculated and compared. Second, an independent samples *t* test compared percent gain means on the FCI and Hake gain means on the FCI. Finally, a two-tailed ANOVA was used to compare overall gains by gender and teaching method.

Table 1 shows that the sample population was representative of the school’s total population in regard to demographics. Some students in the sample population described in Table 1 were not enrolled in regular education classes and, therefore, were not represented in the research.

Table 1

Gender, Economic Status, and Ethnicity School Population Compared to Sample Population

	9^{th}-12^{th} Grades		9^{th} Grade	
Characteristic	*n*	%	*n*	%
Gender				
Male	229	54	71	60.7
Female	192	46	46	39.3
Economically Disadvantaged				
Yes	227	54	63	53.8
No	194	46	54	46.2
Ethnicity				
Caucasian	316	75	82	70.1
Native American	26	6.2	7	6.0
Hispanic	74	17.6	26	22.2
Dual Race	5	1.2	2	1.7

Note. Data were taken from the total enrollment summary at the site and describe general demographics of the sample population.

RQ1: Is there a difference in FCI gain scores of ninth grade physics students who were taught using MI compared to students who were taught using TI?

An independent samples *t* test was conducted to compare FCI percent gains and FCI Hake gains between the MI treatment and TI control groups. The results displayed in Table 2 indicate that there was no significant difference in FCI percent gain scores for the MI and the TI groups or in FCI Hake gain scores for the MI and TI groups. Therefore, the null hypothesis ($H_0$1) could not be rejected. Students who were MI and TI taught showed no significant difference in achievement based on FCI gain scores.

Table 2

FCI Scores by Instructional Type

	Traditional		Modeling			
Instruction	*M*	*SD*	*M*	*SD*	*t(DF)*	*p*
% Gain	12.18	10.33	11.81	14.54	-.201(180.26)	.841
Hake Gain	12.01	10.35	11.59	14.57	-.228(180.26)	.820

RQ2: Is there a difference in FCI gain scores between ninth grade male and female students who were taught using MI?

As shown in Table 3, there was a significant difference in percentage gain for MI girls and MI boys; however, as also noted in Table 3, there was a significant difference between traditionally taught girls and traditionally taught boys.

RQ3: Is there a difference in FCI gain scores between ninth grade male and female students who were taught using TI?

As shown in Table 3, a one-way ANOVA, $F(2,181) = 5.20$, comparing girls to boys under both instruction types, demonstrated a significant gender effect at the $p < .05$ level for both treatment and control groups. The partial Eta squared of the effect size shows that 5.4% of the variance in FCI gains was accounted for by gender. The data indicate that instruction type had no effect on any freshman physics students FCI gains, regardless of gender. Thus, in light of these findings, neither $H_0$2 nor $H_0$3 could be rejected. The type of instruction had no significant effect on girls when compared to boys within control and treatment groups.

Table 3

FCI % Gains by Gender and Instructional Type

	Female			Male					
Gender	*n*	*M*	*SD*	*n*	*M*	*SD*	*F*	*p**	*Partial* η^2
Traditional	40	15.00	11.17	41	9.43	8.72	5.20	.014	.054
Modeling	46	15.29	17.91	57	9.01	10.46	5.2	.039	.054

*(2-tailed)

The data do, however, indicate that girls outperformed boys at the school in their gains in physics concept knowledge during their freshman year, regardless of the type of instruction they received, contradicting the common stereotype that boys outperform girls in introductory physics. In the unanticipated results, there was a significant relationship between gender and content, bearing further inquiry. The data suggest there is a complex relationship between gender and physics content at the site, revealing the potential for further research into student-centered teaching practices that are shown to foster the learning strengths of male physics students at the site in an effort to increase the achievement of all students up to the level of the high achieving females.

Summary of Results

MI had no significant effect on student mechanics concept knowledge in the freshman physics classroom when compared to TI. The data analysis showed there were no difference in the type of instruction that students received and their gains in mechanics concept knowledge. The unexpected results of the data analysis indicated female students at the site had a better understanding of physics mechanics concept knowledge as measured by the FCI regardless of the type of instruction they receive. Female ninth graders outperformed male ninth graders at the school in TI physics classes and physics classes taught using MI. Several variables may implicate and modulate how instruction, traditional and MI, may yield differences of learning outcomes: (a) teacher gender, (b) teacher experience overall, (c) teacher experience with MI, (d) classroom technology, (e) teachers' experience with using technology, and (f) teachers' confidence with using technology. These complex relationships with MI and student achievement warrant further study.

Conclusions

Students who successfully complete a high school physics course are two times as likely to earn a 4-year STEM degree (Tyson et al., 2007). Classroom instruction carries with it a social responsibility to help all students experience success in the classroom and beyond. This study was designed to describe empirically the differences between TI physics achievement outcomes and MI physics achievement outcomes at this site. The study was designed to find the effect of MI on females, who are a typically underrepresented population in STEM careers. Quantitative support for a specific type of science instruction that educationally and socially has positive effects on students in challenging settings such as this could help to narrow the STEM gap for the United States as a whole.

MI in the freshman physics classroom did not produce greater FCI gain scores at the site for participants or benefit females over males in mechanics concept knowledge understanding more than did TI. The results did not demonstrate a statistical significance between MI and TI for freshman physics students at the site, as the literature had suggested. The results also did not demonstrate a statistical significance between females and males within the MI treatment group. Therefore, none of the null hypotheses could be rejected.

Lack of significance in this study suggests looking in new directions to assess intervention efficacy. Findings from this research give rise to several areas for further study. Contrary to prior research, (Mosatche et al., 2013; Quinn & Lyons, 2011) girls are doing better than boys in freshman physics at the school. Many hands-on interventions can be attempted in the physics classroom in addition to MI to effectively improve student achievement. A type of intervention that could be built into the MI curriculum could boost the academic achievement of the male students to the level of the females at the research site, resulting in improved physics achievement for all of the students.

Section 3: The Project

Introduction

The proposed project was designed to address the problem of low student performance in freshman physics. The project will focus on the low performing male students at the site while attempting to have positive effects on all students. Although MI had no significant positive or negative effects on student learning as measured by this study, it does have the supportive research to continue as the primary mode of freshman physics instruction at the school. The limitations of the research warrant the continuation of MI at the site with the intention of improving, modifying, and gathering more data to use for driving change in science education at the school and other schools like it. The project entails building a curriculum plan for the incorporation and evaluation of using computer simulation technology in the MI freshman physics classroom to teach and learn physics concepts. In the following section, the current research is extensively reviewed, followed by a discussion of the implementation and evaluation of the project itself. This section concludes with a description of the local and broad social implications of the project.

Description and Goals

This project was designed to increase the achievement of male students at the school while complementing the MI curriculum to the benefit of all freshman physics students. The proposed project consists of the generation of a curricular framework and a set of strategies to help physics teachers create lessons that incorporate computer simulation technology within the four mechanics units of MI for high school physics. The guide was designed to help teachers generate physics lessons that incorporate effective, tech-savvy, research-based learning opportunities for students. The eventual goal is to provide a simulation technology-based lesson planning guide for the site's physics teacher to complement the MI curriculum for use in the upcoming school year with the freshman physics program. The guide uses readily available software from the Internet, including Physlets (Christian, n.d.) and PhET (Physics Education Technology, 2012). Simulation technology-based lessons emphasize a mode of learning that tends to focus on the achievement strengths of male students (Ausburn, Martens, Washington, Steele, & Washburn, 2009). Research has supporter the use of technology-based lessons and their positive effects on student achievement overall (Ajredini, Izairi, & Zajkov, 2014; Finkelstein, Adams, Keller, Perkins, & Wieman, 2006; Podolefsky, Perkins, & Adams, 2010; Stern, Barnea, & Shauli, 2008; Sun, Wang, & Chang, 2013; Zabunov, 2013).

The goal of the project was to use the literature review to inform the construction of a lesson planning guide that includes a framework and strategies to outline and help teachers create effective, high-quality computer simulation-based lessons. Researchers have shown that numerous computer simulation-based lessons can improve student achievement (Civelek, Ucar, Ustunel, & Aydin, 2014; Nikirk, 2012; Podolefsky et al., 2010; Quillen, 2011; Stern et al., 2008; Zabunov, 2013). The guide uses computer simulations of physical phenomena that are manipulated by the student. Rather than using actual objects (e.g., cars, balls, marbles, ramps, meter sticks, and spring scales) in a laboratory setting, MI can be incorporated to follow these simulations. The student goes through the same MI process, employing a computer simulation in a virtual experiment that can be repeated and manipulated as many times as needed to develop understanding.

The simulation technology lesson planning guide can be used by the site's physics teacher and other secondary physics teachers to help them design and implement quality lessons that fit into a student-centered curriculum, such as MI.

> In creating an educational context that supports productive simulation use for students, the design of and assignment that accompanies the simulation stands out as particularly important. Not only does the assignment influence and structure students' use of the simulation, but is also one aspect that the instructor can directly control. Writing an assignment to accompany a simulation can be a challenging task, as the assignment must be written for the particular context in which it will be used. (Rehn, Moore, Podolefsky, & Finkelstein, 2013, p. 32)

The guide outlines a framework and strategies to help instructors create an original lesson that uses computer simulation technology. Providing only an outline gives teachers the freedom to design a lesson to fit any desired topic or context. Overall, the guide is intended to improve science instruction in physics by incorporating technology into the classroom and to help remove barriers that teachers might face when using computer simulation-based instruction.

Rationale

The American Institute of Physics (2015) reported that fewer than 20% of Arizona high school students took physics, about half the national average. The American Physical Society (APS, 2013) has called upon local, state, and federal policy makers, educators, and schools to provide every student access to high-quality science instruction, including physics and physical science concepts at all grade levels. “Physics and physical science provide context for understanding critical issues facing society today. Further, physics provides a foundation for careers in science, technology, engineering, mathematics, and many other fields” (APS, 2013, “Context and Potential Actions,” para. 1).

Use of the personal computer (PC) is growing worldwide, and many studies over the last 20 years have shown that PC use in the classroom can lead to an increase in achievement in scientific literacy as well as STEM concept knowledge (Cheema & Zhang, 2013). While the gender gap in attitudes toward computer use has closed dramatically in recent years, male students still surpass female students when computers are used to facilitate learning (Ausburn et al., 2009; Dickhäuser & Stiensmeier-Pelster, 2003). Although the quantity of computer-based lessons has shown little impact on STEM achievement, high-quality lessons using computers have shown a significantly large positive effect (Cheema & Zhang, 2013; Voogt, Knezek, Cox, Knezek, & Brummelhuis, 2013). Chien, Chang, Yeh, and Chang (2012) argued, “The advances in contemporary information and communication technologies make science resources much more accessible and make science teaching much more flexible than ever before” (p. 578).

The current project was designed to address the problem of low-performing male students at the site, as indicated by the data analysis of the research. The project also addresses the original research problem of low achievement in physics mechanics knowledge for freshman physics students. To help physics teachers at the site and elsewhere implement quality computer-based instruction, the lesson planning guide outlines effective strategies for the incorporation of computer simulations to help students in understanding physics concepts. Given the results from the research, using computer simulations in physics instruction could help bring male student achievement levels on the FCI in line with the female students at the site, with the ultimate goal of increasing the number of students willing to pursue a career in a STEM field. This, in turn, would effect positive social change by including underrepresented people in STEM professions, expanding the perspectives and creativity of professionals in the field.

Review of the Literature

Overview

Science education has provided a platform for innovation in teaching and learning. The use of technological equipment in the science classroom has the potential to change teaching in a positive way for 21^{st}-century students (Quillen, 2011). Many agencies and most all state and national standards have recommended that teachers should use technology for science instruction, yet few science teachers do so regularly in their classrooms (Cheema & Zhang, 2013; Hakverdi-Can & Dana, 2012; McNally, 2012; Voogt et al., 2013). Computer use by teachers as well as students is shown to have positive effects on student achievement (Cheema & Zhang, 2013). McNally (2012) asserted, “Some recent programs have shown that technical innovation and computer applications have a role to play in improving STEM education” (p. 49). Students tend to like it when computers are used in the teaching process and many feel that computer technology allows student to take a more proactive role in their learning (Kubiatko, Haláková, Nagyová, & Nagy, 2011).

Foundational Theory

Knowledge is constructed by individuals through their experiences, and this "cognitive development" can be fostered by guiding learners through experiences that illuminate content (Piaget, 1950). Piaget's theory of cognitive development has served as a cornerstone to almost every experiential learning theory developed over the past half century, including constructivism, guided inquiry, and modeling (Hestenes, 1985; Kretchmar, 2008). Adolescents are in a natural transition to more abstract thinking or formal thought (Inhelder & Piaget, 1958). The teen years are an ideal time to increase student experiences with the intent of developing more in-depth and critical thinkers (Inhelder & Piaget, 1958; Tahir, 2010). Learners naturally progress from concrete cognitive processes to more abstract formal cognitive processes during adolescence (Inhelder & Piaget, 1958; Lawson & Wollman, 1976). Piaget (1950) determined that this transition could be positively impacted when learners are given authentic scientific problems to work out. Scientific knowledge is built and expanded through the translation of prior knowledge to new experiences, with the goal of their solving problems at the forefront (Tahir, 2010). Both real experiences and computer-based, virtual experiences have been found to be effective for student formal thought development in the 21st century (Ajredini et al., 2014; Podolefsky et al., 2010; Zabunov, 2013).

Classroom Computer Use

Personal computer use by teachers and students in the classroom leads to positive effects on scientific literacy and STEM achievement (Cheema & Zhang, 2013). Looking at data from the 2011 TIMMS, Cheema and Zhang (2013) found that both quantity and quality of computer instruction had positive effects on science literacy and problem solving, although quality had a much larger effect. The overall effect of computer use was positive but not as impactful as socioeconomic disparity or teacher quality data. Indeed, teacher quality is a key factor when it comes to student achievement, particularly when it comes to computer use in the classroom. Hakverdi-Can and Dana (2012) examined exemplary teachers who received the Presidential Award for Excellence in Science Teaching and found students excelled in using computers for learning science when their teachers were enthusiastic and confident about using computers. Teachers who use student-centered approaches such as inquiry, cooperative learning, discussion groups, and computer-based learning projects made up a majority of the 92 survey respondents (Hakverdi-Can & Dana, 2012). The respondents, most of whom were categorized as humanistic-type teachers, commented that when they have knowledge of a specific type of classroom technology they will use it. When teachers are supported in their technology use and understanding, the student benefit is profound (Fuller, 2000).

Teaching and learning science by through technology in learning environments has become a highly sought method of scientific classroom instruction, according to Sun and Looi (2013):

> Research has produced much evidence that demonstrates such learning environments have great potential to facilitate the development of cognitive and metacognitive strategies in pupils, and to improve student's conceptual understanding, as well as aspects of motivation, collaborative competence, critical thinking skills, and self-regulated learning skills. (p. 73)

Sun and Looi (2013) developed and tested a web-based inquiry simulation with modeling and visualization technology (WiMVT) to provide students with a technological tool for developing inquiry and critical learning skills. The pilot tests indicated average results for modeling and inquiry but showed that the system, with further development, could have a positive impact on students' key scientific thinking skills (Sun & Looi, 2013). In general terms, the authors determined that students who were taught using visual computer technology did not score better than traditionally taught students on multiple-choice science tests but scored significantly higher on tests that involved interpretation or explanation of answers (Sun & Looi, 2013).

Computer Use and Gender

Early studies showed a significant gap in gender and computer confidence, a gap that was greatest with high school aged females choosing to take computer courses much less often than did male students (Dickhäuser & Stiensmeier-Pelster, 2003). Males were much more interested and skilled in computer use than were females, and male secondary students used computers more for leisure, play, and entertainment (Shashaani, 1997). The gap was much less profound in young children than in adolescents, suggesting that social influences contribute to the change (Shashaani, 1997). More recently, researchers have found mixed results with regard to male and female attitudes in computer use. Females have recently matched or surpassed males in creative computer use and writing applications, but boys continue to outperform girls in technical computer use, particularly in the areas of STEM (Kubiatko et al., 2011). Typically, students' PC skills and positive attitude toward computers are tilted in favor of males, but people regardless of gender are using computers more and more, and time spent using computers has the greatest impact on student attitudes (Dickhäuser & Stiensmeier-Pelster, 2003; Ilomaki & Rantanen, 2007; Kubiatko et al., 2011).

Using computers instead of taking part in real laboratory experiences can be both effective and low-cost, and many educational institutions are utilizing computer simulations to teach students (Ausburn et al., 2009). Technological self-efficacy is the single greatest hindrance to learners in using computers educationally (Ausburn et al., 2009). Interpreting the results from cross-study findings, Ausburn et al. (2009) suggested that "males and females may be differently affected by virtual reality simulations and that females may be less comfortable, confident, and capable in virtual learning environments, particularly when the environments are highly technical and visually complex" (p. 52). High-tech and visual components are common in many computer simulations used for science concept teaching and learning. These components can affect both performance and observed perception of performance in students using technology as a basis for learning concepts (Ausburn et al., 2009). From the 1980s to 2000s, research showed females had lower self-efficacy in computer use, a trend that has been changing over the last decade (Ausburn et al., 2009). In the age of smartphones, females are becoming more comfortable with using computers (Ausburn, et al., 2009). One area of weakness that persists for females is spatial and mental rotation ability, a deficiency exacerbated in virtual reality computer simulations (Ausburn et al., 2009). Computer simulations have the ability to give students a real and simplistic way to guide themselves toward uncovering the essence of how a system functions and to understanding in depth the relationships between various components of a phenomenon (Ausburn et al., 2009).

Although computer technology allows all students to take a more proactive role in their learning and achievement, for many reasons the response toward computer use in STEM classrooms has been slow (Kubiatko et al., 2011). Greater amount of time spent using computers by students has the greatest impact on student attitudes regarding computers regardless of gender (Kubiatko et al., 2011). Adolescent males tend to have more positive attitudes in general toward computers than adolescent females (Kubiatko et al., 2011). Data from 659 high school student questionnaires showed a positive overall attitude toward computer use (Kubiatko et al., 2011). Ninety percent of students surveyed enjoyed using a computer, 75% of students enjoyed using a PC for learning, 85% considered PCs very useful in school, and two thirds indicated they would like to use PCs in all subjects (Kubiatko et al., 2011). Female respondents had more anxiety about PC use than did their male counterparts; however, with increased social media use, females are quickly closing the confidence gap (Kubiatko et al., 2011).

Computer Simulations

Computer simulations have the potential to motivate students, particularly male students, because they are perceived as a game (Sun et al., 2013). Many simulations use system-generated messages to show learners where potential problems may occur and students can identify the problems and make immediate corrections (Sun et al., 2013). This is particularly useful to judicial-thinking male students (Sun et al., 2013). They also give much more detailed information than textbook readings with pictures or diagrams to help visually explain the text (Sun et al., 2013). Sun et al. (2013) researched bridge-building computer simulation software and senior high student populations to get a better view of the relationship between the simulation tool and student learning. The authors postulated, "Computer simulation users can freely control operational factors and simulation results, repeat processes, make changes, and learn from simulation environment feedback" (p. 309). Students have been forced to focus on test scores and excelling at multiple-choice, one-correct-answer-only types of assessments (Sun et al., 2013). Such tests contradict scientific thinking and the scientific method of observing, creating, experimenting, and explaining (Sun et al., 2013). Computer simulation programs help students carry out complicated experiments that would be difficult or impossible to do in reality (Sun et al., 2013). Students can carry out detailed experiments and quickly use developed knowledge to alter the simulation and to modify predictions about the outcome (Sun et al., 2013). Computer simulations, when used effectively, are a tool to help students connect new and prior knowledge (Civelek et al., 2014; Nikirk, 2012; Quillen, 2011; Sun et al., 2013). They help students construct knowledge through trial and error which leads to modification and changes in approach to reach an objective (Sun et al., 2013). This is a parallel process to doing real science. Computer simulations allow students to perform experiments that they might not be able to do in the real-world with the benefit of celebrating success like the real-world (Sun et al., 2013). They also afford students with various learning styles to approach the problem solving arena in a way that best suits their means of making sense of the world. This learning by doing part of computer simulations helps students and educators allow students to gain understanding of concepts in a way that suits them (Civelek et al., 2014; Nikirk, 2012; Quillen, 2011).

Hands-on science activities will stimulate greater understanding of concepts then passive learning formats (Ajredini et al., 2014). The benefits of real experimental learning for students are investigating and creating an original experiment; the main drawbacks are time restrictions and the physical human activity of repeating the experiment the same way multiple times (Ajredini et al., 2014). The primary benefits of a simulation are that students have more time to discuss their observations and make sense of them (Ajredini et al., 2014). Simulation students are also able to repeat procedures exactly the same way as many times as they need to until they understand the phenomenon (Ajredini et al., 2014).

Ajredini et al. (2014) compared three groups in learning static electricity concepts. The experimental group used a simulation from PhET, the real group conducted real experiments using balloons, rods, and cloths, and the control group learned the concept by teacher lecture. The authors found no significant difference between the simulation group and the real experiment group on pre-post concept testing. Ajredini observed that both real and virtual groups learned the concept while removing their misconceptions about static charge. The control group had significantly lower gains in concept knowledge and retained many of their misconceptions (Ajredini et al., 2014).

It is not practical to try to teach through experimentation the many complex aspects of certain physical phenomena (Zabunov, 2013). A student cannot observe all vector and scalar quantities simultaneously in a real-time laboratory experiment (Zabunov, 2013). Zabunov (2013) found that computer simulations of pendular motion help students improve in the areas of forming concepts, improving the comprehension of concepts, and understanding the relationship between concepts. A computer simulation allows the observer to watch images of phenomena repeatedly while also observing changes in numerical quantities as the images change. This gives students the ability to change, modify, and compare to baseline conditions a phenomenon and change the conditions to make new observations as necessary (Zabunov, 2013).

The Physics Education Technology (PhET) project at the University of Colorado, Boulder, has developed, tested, modified, and researched more than 50 physical science computer simulations (Finkelstein et al., 2006). These simulations provide virtual visual feedback to users who are interacting with images of physical science concepts (Finkelstein et al., 2006). PhET’s ideas for classroom use suggest a constructivist approach to using computer simulations effectively (Finkelstein et al., 2006). A guided inquiry approach, similar to modeling, should be used in conjunction with computer simulations to guide students to build personal explanations of physics concepts (Finkelstein et al., 2006).

Computer Simulations and MI

Computer simulations are not a singular way to learn but a helpful piece of a multiple-approach learning puzzle (Stern et al., 2008). Stern et al. (2008) observed that when the simulations are used as a stand-alone method of instruction they are ineffective but when incorporated into a student centered, multiple-method curriculum they can be highly effective. Students will hang on to their thoughts from experiences in life even after being taught or even shown the correct, contrary explanation. Teachers can employ (a) models; (b) analogies; (c) diagrams; and (d) simulations to help students understand difficult scientific concepts (Stern et al., 2008). Computerized simulations are both student-simulation interactive and possess detailed images that respond to the users command providing users with a means of embedding visual knowledge into their current cognitive understanding of a concept. Students taught the concept of kinetic molecular theory using a computer simulation program scored significantly higher than traditionally taught students on a pre-post concept test (Stern et al., 2008).

Recent advances in the visual aspect of computer technologies have brought forth deeply detailed imagery even on a basic personal computer (Podolefsky et al., 2010). These types of computers are now the norm in most schools in the United States, and a large number of computer simulations are being used for science education worldwide (Podolefsky et al., 2010). Podolefsky et al. (2010) stated, “PhET sims are a substantial (~85) and growing suite of computer simulations for engaging students with science content. The sims are being freely distributed from the PhET web site, with roughly 10 million uses in the past year" (p. 1). Most of the currently available simulations are within the physical sciences.

Researchers at the University of Colorado developed and studied PhET simulations within the context of engaged exploration and analogy both contexts are an integral part of MI. Computer simulations give students a visual tool where they can make changes to a physical scenario and instantaneously observe the effects of those changes (Podolefsky et al., 2010). In trying to answer a broad conceptual question, students can explore in their own way the cause-and-effect relationships within a physical system (Podolefsky et al., 2010). This is the same way that scientists solve problems in the real world. The analogy aspect of PhET simulations allows students to construct new conceptual knowledge building upon prior knowledge in much the same way as MI (Podolefsky et al., 2010). Computer simulations are engaging, interactive, constructive, accessible, and visual models that provides users with immediate useful feedback to help guide students toward meaningful understanding of scientific concepts (Finkelstein et al., 2006; Podolefsky et al., 2010; Stern et al., 2008). Smetana and Bell (2012) stated, "Computer simulations are most effective when they (a) are used as supplements; (b) incorporate high-quality support structures; (c) encourage student reflection; and (d) promote cognitive dissonance" (p. 1337) When used in conjunction with MI, computer simulations could guide students to explore scientific problems the way that scientists do in the real world, leading to increased STEM achievement and confidence toward choosing a career in STEM fields (Smetana & Bell, 2012).

Limited information was provided in the literature review for the project study using the Walden University Library, the American Institute of Physics archive, the American Modeling Teachers Association archive, and Google Scholar. The literature search included the following terms: *science (education), technology, computer use, technology and gender, male student computer use, Technology and STEM education, computer simulations, physics simulations, simulations and real-labs, teacher use of technology, technology and student attitude.* The extensive literature review revealed a consistent theme. While the resources listed are not exhaustive, the wide array of current studies and information reviewed began to show redundancy of results, conclusions, and themes. I assumed that saturation was reached to provide sufficient and adequate support of the doctoral project study. Computer simulations have positive effects on student achievement. This finding and the results from the research lead me to the implementation of the project discussed below.

Implementation

The data from the research revealed that female students at the site significantly outperformed male students in physics mechanics concept knowledge as measured by the FCI, regardless of the type of instruction that they receive. The literature review supported computer simulation use in the classroom as a means to stimulate understanding and interest in STEM concepts for all students. The review of the current literature also suggested that computer use involving visually inquiring tasks, such as simulations, are particularly beneficial to male students.

After completing the computer simulation lesson planning guide, I will issue it to the school's physics teacher, and a one-hour training session will take place to familiarize the physics teacher with the guide and its potential for generating quality lessons that incorporate computer simulation use into the MI curriculum. The freshman physics teacher at the school will be tasked with creating four lessons that use a computer simulation to illustrate a physics concept for students. I will be available to support the physics teacher thorough the lesson building process. Lessons will be created and implemented by concept and in the sequence that they are presented in the MI curriculum. The concepts that will be included in the projects evaluation are constant velocity, acceleration, forces, and simple pendula. The school's physics teacher is free to implement as many simulation lessons as he is comfortable with; however, only the four primary concepts listed will be evaluated as part of the project.

Potential Resources and Existing Supports

For the research the properly obtained resources included the site, a consenting teacher, and proper written permissions to conduct research form the site administrator and the Walden University Institutional Review Board. A presentation of the research was also given to the school superintendent and the school board of directors to foster a supportive relationship between key stakeholders and the researcher. This supportive environment has led to complete support for the project implementation by all stake holders at the site.

A new 30-student Science and Mathematics Computer Center (SMCC) was built in an empty classroom with funds secured from an Arizona Science Foundation grant.

The SMCC will be used by the school's science and math students as a technological complement to their instruction, including the freshman physics students. All of the simulations used in physics for the project are available for no cost at the PhET website. The PhET site also includes teacher support and instructions to help teachers use the simulations in a way that has been tested for effectiveness. Other resources include the school's physics teacher, who is entering his fourth year as a freshman physics teacher and second year as a MI teacher. All modeling participants have access to all of the MI resources, including the FCI and other assessments from the MI website (www.modeling.asu.edu). The previous two cohorts of freshman physics students were an essential resource for the research, and the project itself will be implemented with the incoming 96 freshmen.

Potential Barriers

One potential barrier to the project is time. The school has a seven-period day for students, and each class meeting is 55 minutes. The site also uses a 4-day week with only the minimum required 144 student days. To change from a teacher-centered approach to a MI student-centered approach for the research required careful planning to be effective within the current time restrictions at the school. Implementing the use of computer simulation technology for the project will have additional adverse effects on time management.

Another probable barrier to project implementation is the uneven competences in basic computing skills of entering freshmen. Although the district's middle school now requires computer classes for all grade levels, such is not the case for technical computer use. Particularly missing is the use of computers for STEM subjects. STEM teachers will need to take on the critical task of improving students' computer competence just so that they can begin their high school STEM experience. While teacher competence in computers has been shown to be a major barrier to classroom computer use, the school's physics teacher (personal communication, May 11, 2015) is highly comfortable using technology for all purposes, including education.

Proposal for Implementation and Timetable

The proposed project will be implemented at the start of the 2015-2016 school year during the first teacher planning week. The guide was given to the school's physics teacher over the summer, and the physics teacher will create four lessons in different mechanics concept areas that use the guide to incorporate computer simulations from PhET into a lesson. Implementation of the lessons will take place over approximately 18 weeks. The students will take the FCI as a pretest before any instruction and then again as a posttest immediately following completion of the last mechanics unit for freshman physics. Each simulation lesson will be evaluated following its completion using the modeling concept quizzes that are part of the MI curriculum. The teacher and I will use the quiz data to evaluate and modify the effectiveness of the simulation-based physics concept lessons. This continual evaluation, reflection, and modification throughout the project will provide the teacher and researcher with information and data to drive effective educational change in physics.

Roles and Responsibilities of Student and Others

Students have the responsibility of coming to class and trying to engage with the content by participating in discussions, asking questions, and building confidence in using the simulation technology required. The physics teacher has several responsibilities:

- Understanding physics content in an in-depth manner, as well as having knowledge of the common misconceptions that high school freshmen will have with that content.
- Having a solid grasp of the MI method of teaching physics and being prepared to deliver high-quality, student-centered MI lessons each day.
- Administering the FCI as a pre- and posttest and all of the benchmark tests and unit quizzes from the MI curriculum.
- Collecting, recording, and sharing that data with the researcher and other stakeholders
- Becoming familiar with the lesson planning guide framework, strategies, and the PhET resources and simulations that he will utilize with his students for the four lessons that will be evaluated by the researcher.

Project Evaluation

Analysis of FCI results following the project will be the largest means of overall project evaluation. Results from the MI concept quizzes at the end of each simulation incorporated lesson will be used to assess the effectiveness of the instruction method. All data can be analyzed in isolation and compared to MI data without simulation use and the traditional control group data. Concept quiz results following computer simulation instruction will provide a glimpse into its effectiveness for student learning of the immediate concept. Increased FCI gains once instruction is modified to a more student-centered approach would indicate that the changes made by the site's science department have been effective and should continue.

Past research has supported the FCI, a goal-based formative evaluation, as a valid measure of physics students' mechanics concept knowledge (Halloun & Hestenes, 1985; Lasry et al., 2011; Nieminen et al., 2012). The overall goal of this research project was to increase FCI gains at the site on average to greater than 20%. Students' gains of 20% or greater on the FCI would show classroom instruction was effective. Increasing content confidence and understanding in freshman physics for students at the school could lead to greater success in STEM subjects throughout high school. Graduating high school with a strong STEM education could lead to future careers in important STEM fields. The goal of the research is to continually improve STEM education for all students at the school.

Implications Including Social Change

Providing adolescent students with a strong foundational physics concept understanding at a time when they are naturally transitioning to higher order thinking will be beneficial to their confidence, enthusiasm, and ability to pursue a challenging STEM educational pathway. Given that student success in freshman physics can lead to greater confidence and enthusiasm toward STEM, this project was designed to improve student ability in understanding complex physical phenomena.

Implication of Project on the Local Community

This project was focused on a specific local community of typically underrepresented students in STEM achievement. Physics is the foundation of all STEM content, and a strong understanding of physics supports STEM achievement throughout life. STEM careers are among the most needed and highest paying vocations in the world. Students at the school will benefit from this project by increasing their scientific literacy and their potential for meaningful, gainful employment in the future. This is also a direct benefit to the families and the economics of the area. Quality teachers and administrators place student success at the front of their educational philosophy. They will benefit from this project by learning ways to help students experience success in essential and critical subject areas. Furthermore, teachers can directly learn ways to effectively incorporate 21st-century skills into their classroom. Graduates from the site will have the foundations and some of the skills needed to be successful in a technological world, a direct benefit to the student, their teachers, administrators, their local community, and society as a whole

Far-Reaching Implications of the Project

This project provides students with a self-guided means of understanding a challenging subject. A successful experience in physics can remove many barriers to learning other sciences. The project helps students connect computer technology to scientific understanding, which can be a critical skill in modern society. The research project introduced two types of modern, student-centered instruction in an effort to improve their confidence and competence in STEM. Having a strong understanding of STEM concepts and their importance will guide students to a life-fulfilling career in the field. Having greater variety of people pursuing STEM will give the field a deeper new perspective propelling discovery and innovation.

Conclusion

The project was developed based on the results of the research. Incorporating computer simulations into the MI curriculum with the intent of benefitting all freshman physics students at the site, particularly computer-confident males, was a logical direction of this project to proceed. In order to preserve the autonomy of the teacher, I created a lesson plan guide with only a framework and strategies. The teacher is tasked to use the guide to develop his own lessons, which include use of a computer simulation to teach a physics mechanics concept. This student-centered approach to incorporate simulation technology fits well into the MI curriculum that I examined for the research. The results provided justification for continued use and further data collection on MI at the school. One of the key components of MI and good teaching as a whole is reflection. Continued modification, evaluation, and reflection will be a daily exercise at the site in the ongoing effort to improve scientific literacy for all of its students.

Section 4: Reflections and Conclusions

Introduction

This project study was designed to promote positive social change by increasing the level of physics concept knowledge to promote a viable STEM career pathway for a typically underrepresented cohort of high school freshman physics students. The FCI pre- and posttest were used to collect quantitative data in mechanics conceptual understanding for physics. Results from MI were compared to traditional instruction in beginning physics at the school. The data revealed that MI had no significant benefit for any students, including the typically low physics achieving female students. While the findings from this study did not provide strong support for MI, they did show an unexpected significant gender gap in physics achievement in favor of the school's female students. I used the findings to support building a project that supported physics education while focusing on the technological learning strengths of male students in the school's freshman physics classroom.

Project Strengths

Quality instruction is often the greatest factor in promoting high student achievement gains. This project study was guided by a need to promote research-based, highly effective classroom instruction for freshman physics. The project's strengths include quantitative data analysis from the FCI, which carries with it a high degree of validity and reliability in measuring effective instruction and student mechanics concept understanding. Though the FCI is a multiple-choice instrument, all of the alternative answers are based on common student misconceptions about physical phenomena. The

FCI has been administered in thousands of physics classrooms worldwide since 1992; compiled data have been used to increase the intended effectiveness of the measure. Physics education researchers at Arizona State University have been utilizing a national FCI database to develop the test, and there is an exhaustive archive of valid research that supports using the FCI to measure instructional quality. I used FCI data to directly evaluate and compare differences in instruction and then use the data to drive change in the classroom.

The data were collected from the school's archive and were de-identified prior to analysis, strengthening the project study by maintaining my independence from the participants. I was able to use collected FCI data gathered from the school's regular annual teacher evaluation process, and thus independent from researcher bias and manipulation. The school's physics instructor collected the data without his knowing they would be used in my project study. All data for the research were collected ex post facto, simplifying the analysis process and the protection of the participants who provided the data, giving strength to the study by separating the data and the participants from the research.

An additional strength of the project was identifying the unexpected number of super-high achieving freshman physics female students. Researchers have shown that male physics students typically outperform female ones in physics achievement; however; the data from my project showed the opposite. Female students at the site outperformed the male students in physics concept understanding, regardless of instructional type. Women and girls are greatly underrepresented in STEM fields, and more are needed in STEM to provide a different perspective in solving some of today's important problems related to STEM. This strengthens the study in two ways. First, the results further supported the unbiased nature of the study by generating unintended results opposite of what was expected while supporting the null hypothesis. Second, the results enabled me to identify a trend that can lead to powerful positive social change. Education can be used as a key change agent for social issues, including addressing the issue of underrepresentation of women in STEM. The school's female students are achieving in physics. Understanding what is promoting this phenomenon could help balance the tables between male and female students when it comes to future careers in STEM fields.

A final strength to the project was its incorporating MI to empower students to be in charge of their own learning and scientific literacy. Regardless of the results of the research, MI is a student-centered approach. Moving students in freshman physics from a teacher-centered classroom to a student-centered classroom may well result in a positive educational change. Student-centered approaches to science education have produced positive results across multiple studies. A natural progression of scientific inquiry, MI guides students to simulate the process of real-world science. They learn science by doing science and investigating the natural world through experimentation. Students formulate, modify, and defend their models to peer review, helping them understand what is involved in a legitimate scientific explanation. Through action, MI students develop critical scientific skills that can be applied for a lifetime of endeavors grounded in scientific literacy.

Recommendations for Remediation of Limitations

One major limitation of the study was the possible differences between the control group and the treatment group, who were matriculating one year apart. Background knowledge and achievement capabilities were relatively unknown. By having the two groups measured in isolation, the data may not give a realistic picture of how the achievement of the groups on the FCI is purely based on instruction and not potential ability. This difference might be remedied by including an eighth grade science achievement test score into the analysis, comparing the potential for achievement in both cohort classes studied. Having some baseline data on each group’s scientific ability could be used to factor in a difference in potential of student achievement into the analysis. Another remedy might have been to conduct the study at a larger school and choose the control and treatment groups randomly within the same cohort.

Another limitation was that the small limited convenience sample studied did not provide the data set from a large random sample needed for generalization of results to a larger population. The data were all collected from one school and one teacher, limiting the results to an isolated population with similar demographics. The limited sample could be utilized to continue data collection from future cohorts for MI in physics at the site. Continuing to analyze the FCI data from MI freshman physics students could in time reveal an upward trend. Insufficient data were produced in this study to add to the database of MI supportive research. As the physics teacher gains expertise in MI and incorporates simulations from the project, student FCI gains might begin to grow.

A final limitation was the use of a single measure to show achievement, the FCI. The research may have had more significant results if more achievement measures were compared in the analysis. Only the FCI pre- and posttest was used to measure of instructional effectiveness and student achievement in physics concept understanding for the students. An important goal of the project was to prepare students at the school for a successful career in STEM areas. The literature showed that a primary factor in student success in STEM subjects was attitude toward learning STEM. For the project, multiple sources of achievement data will be used, including, ultimately, the FCI.

A student attitude survey about physics could yield some additional data in support of the projects effectiveness through the strengthening of student self-efficacy regarding STEM. If students leave freshman physics with a confident attitude about pursuing STEM knowledge and careers, it could have a positive effect on the social issue of low STEM representation for students at the project site and students elsewhere like them.

Scholarship

I have learned that scholarship is a rich and demanding endeavor that is driven by the desire to enact positive changes in society. The demands of a scholarly literature review were unexpected and rewarding. One must not only read credible literature but must saturate everything that is available on the subject. Scholarship comes with the understanding that no study is perfect, but many imperfect studies can be used to find support for an idea and, most importantly, a plan of action. As an educator, scholarship has guided me to review in-depth what other researchers in education have done and to use it to enact change where it is needed most to benefit students. I have learned the joy and importance of seeking knowledge and sharing that newfound understanding with others. Scholarship has reignited my passion for education, providing me with the knowledge and skills needed to lead teachers to work toward a common goal that benefits their students and other stakeholders. I have learned that scholarship is a difficult and challenging process that requires time, patience, persistence, resolve, conviction, and passion. This project study has required from me all of those things; however, the rewards of leading teachers and students to discover success in the classroom are profound.

Project Development and Evaluation

This project was developed to drive social change by improving STEM education for students. I discovered through years of direct observation of students as a classroom science teacher that the problem existed at the site. My literature review revealed that the problem was not just at my site but was a national issue with tremendous social implications. As a high school science department chair, I am directly responsible for science education of students in Grades 9 through 12. I chose to research ninth graders because I believed improving their science experience at the start would have a lasting effect for the next 3 years. As I began to read and learn about effective physics-first teaching methods, I discovered ample research on MI and other active learning methods that supported its use in the freshman physics classroom. I wanted to quantify the effectiveness of the first year of high school science instruction at my school; thus, using data from the FCI seemed logical. Because the foundation of the entire high school science sequence was physics, I wanted to enact research-based improvements for this critical area. The data from the FCI were already collected and archived. Using existing data made it possible to give the participants complete anonymity and protection. My hope was that the FCI data from freshman physics would yield high gains for the students. That result would justify to all stakeholders expanding the use of MI to chemistry and biology. My intended project for this study was implementing MI in the chemistry classroom at my school.

The results from the research were completely unexpected and revealed the exceptional female science students at the school. This insight found in the data caused me to step back at rethink how I can further support students and their teacher in the freshman physics classroom. The results also led me to develop a project that might boost physics achievement among the school's male freshman. An extensive literature review began to show a common theme for student success in physics and revealed a national shortcoming. Incorporating technology into the science classroom was a recurring, effective component of the research on STEM education, particularly in physics. As the literature review progressed, a specific type of technology, computer simulation, was shown to be most beneficial to students, primarily males. I discovered an abundance of supportive literature on simulation use in the science classroom, which led to the project. I wanted to incorporated computer simulations into the freshman physics classroom while keeping the autonomy of a good physics teacher intact. A lesson planning guide that introduces the teacher to several researched physics simulations but allowed for the personal development of the lesson by the teacher seemed to be a project that would meet my goals for freshman physics. The basis of the framework and strategies for this project came from several studies on classroom use of computer simulation, including a broad national data collection on PhET simulation use conducted at the University of Colorado, Boulder.

Leadership and Change

I have learned that, although most people fear change, leaders must enact it. Leaders must guide a group of people to achieve a common goal that benefits many. Teachers need good leaders to help them achieve the common goal of helping kids become successful adults. The doctoral process has taught me several things about leadership in education. Leaders must be consumers of research and have a broad understanding of effective educational practices. They must be fearless in enacting change in schools to the benefit of students. Good leaders must be good listeners. Teachers have ideas and concerns and a leader must listen to his or her peers who are on the front lines of the educational process. Listening to teachers and acting on the discourse will not only help guide the group to work toward a common goal; it instills mutual respect and personal accountability of group members to the educational success of their students.

Analysis of Self as Scholar, Practitioner, and Project Developer

This doctoral journey has been life changing, and I see myself through a different lens. As a scholar, I have learned how to immerse myself in literature to discover problems and directions for positive change. A literature review helps a scholar understand complex problems and gives him or her the data and information needed to develop complex solutions to those problems. I have gained confidence in my abilities as a scholar to use legitimate research in education to drive my decisions and goals. I view educational literature with criticism and understand how to gather relevant literature that illustrates all available perspectives. In understanding the data and perspectives of an issue, I am able to make an informed decision that has a greater likelihood of meeting the desired educational results.

As a practitioner, I have learned how to be confident in my abilities to gain understanding through research and use that understanding to drive positive change in schools. I have spent a huge amount of time and effort in completing this project and have realized more than ever the power of knowledge and conviction. I have learned that researching, questioning, experimenting, collecting data, analyzing, and basing action on the findings are not just part of science but integral in educational practice. My experience as a practitioner of research has given me the understanding and experience to apply to a wide variety of educational problems.

As a project developer, I used data from my research to discover where a project was most needed. I tried to develop a project that addressed the overarching need of improving freshman physics instruction for all students while focusing on the learning strengths of male students addressing a specific need discovered by the research. I developed this project based on an extensive literature review and tried to keep the project focused and measurable. Another important aspect of the project was careful attention to the physics teacher’s needs. Teachers need to create in order to develop their craft; it was important that this project did not hinder that creativity but encouraged it. By my providing the teacher with a framework, strategies, and resources for the project and allowing him to develop his own original lessons, both goals were met. Developing this project has been not only a benefit to physics students at the school but has helped to build a lasting professional relationship between the teacher of potentially hundreds of young scientists and me as a leader.

Project's Potential Impact on Social Change

This project had a direct impact on a typically underrepresented group of students in the field of STEM education. The project was designed to improve physics education at the school leading to success in high school science and eventually to a career in a high demand, high-pay STEM career for these students. This project could be used by any school with similar demographics to improve their physics instruction and leading to the same end result. By broadening the representation in STEM a new perspective will be present in the search for solutions to some of the world's greatest problems.

Implications, Applications, and Directions for Future Research

Physics is the foundation of all other science subjects, and success in physics can lead students to success in all other scientific endeavors. My doctoral project study focused on improving classroom instruction in physics at the beginning of students' high school experience. This study could be applied to most high school physics classrooms. I learned that classroom instruction is a key component of student success, and changes to classroom instruction will have an immediate impact on a student. Additional data will continue to be collected at the site and will be used to drive changes in instruction in the school freshman physics classroom. Future research may include analysis of freshman MI physics student ACT scores in science as juniors compared to the traditionally instructed physics students from the prior year. Students at the site could be followed through high school and beyond to find if the end goal of the research, a STEM career, has been realized by more of these students against the national trends.

Conclusion

The research compared MI to traditional instruction for freshman physics students. The intention of the research was to improve instruction in physics for all freshman students, particularly females. The data from the FCI showed that had no effect on concept knowledge for any students, regardless of gender. The data analysis did indicate a significant gender effect no matter what type of instruction was used. The research yielded unexpected results by revealing a population of female physics students who defied the research by outperforming males in physics achievement. This unique finding inspired the project that focused on using computer simulations in the physics classroom to bring male student achievement at the site up to the level of the female students. A review of current research revealed that computer simulations are beneficial to all students learning physics, but male students seem to respond with the highest levels of achievement. Success in science at the high school level may, in turn, lead to a successful career in a STEM area for the school's underrepresented students.

The project involved freshman physics students in a small rural high school who were beginning their adolescence and their age of formal thought. In addressing issues in science achievement at this early critical age, I hope to improve the science education of these students providing them with the STEM tools they need for future success. I also hope that this project will lead to a first-rate science education for future students at the school and others like it. Though the research in MI did not have the anticipated results, it did provide insight into a population where females dominate physics achievement against the odds. The overarching purpose of this project study was to find effective ways to improve STEM achievement for all students and provide data to the represent rural populations. Low STEM achievement is a national problem, and thus far, large-scale educational policy implementations have not shown significant positive effects on the issue. Improving science education at the local level and broadening successful practices may provide the best chance of improving STEM achievement, confidence, and literacy for all American students.

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Appendix A: Project Study

PhET SIMULATION LESSON PLANNING GUIDE WITH FRAMEWORK AND STRATEGIES

Introduction

This lesson planning guide is designed to give high school physics teachers a tool for individual generation and implementation of lesson plans that include a computer simulation from the PhET interactive simulations web site (http://phet.colorado.edu/). The PhET site developed at the University of Colorado, Boulder, offers a plethora of teacher resources for lesson development using computer simulations. PhET simulations are free to use and can be accessed through the PhET site or can be downloaded and used by students without an internet connection. This guide is designed to give teachers a framework to use while designing their own lessons that incorporate computer simulation use in the lesson. Also included in this guide is a set of general strategies to help teachers create effective lessons based on a specific chosen simulation. The simulation lesson planning guide is designed to give physics teacher's autonomy to create their own unique lesson that fits into the Modeling curriculum and provides the user with the ability to adapt the strengths of the teacher's personal teaching style.

Purpose

Teacher use of computer simulation technology in the science classroom can be an excellent way to provide a fast, easy, low-cost, and safe, hands-on activity for students to experience. Computer simulations have demonstrated similar positive learning outcomes to actual laboratory experiments and typically require less time to carry out with fewer mistakes and more accurate results. This lesson planning guide is designed to help provide support to high school physics instructors in the creation of meaningful lessons that utilize computer simulation technology to virtually demonstrate physical phenomena to their students for investigation on concepts. The guide includes a unit outline that incorporates specific PhET simulations into the MI mechanics sequence. It also includes a framework for use when developing a lesson that shows flow between the assignment, the simulation, and the model. The three elements of the framework flow diagram surround a specific mechanics concept which is the central theme to the lesson.

Continuous professional development will occur between the researcher and the freshmen physics teacher will occur throughout the first year of implementation. The meetings will take place two times for each of four lessons that use simulation technology. The first session will involve developing the lesson utilizing the framework. Following the first session the teacher will conduct the lesson and deliver the formative assessment from the MI curriculum to the students. In the second session the teacher will reflect upon the lesson and the formative assessment results with the researcher. Based on the observations and data modifications to the lesson will be made as well as notes for the improved development of the next lesson that involves student use of a computer simulation.

Project Goals and Learning Outcomes

1. To help physics teachers develop effective lessons that utilize computer simulation technology.

2. To familiarize physics teachers with the computer simulation resources available to support lessons in mechanics.
3. To share with students, administration, stake-holders, and other physics teacher’s lessons and data that support simulation use as a tool for effective physics instruction.
4. To stimulate the learning strengths and interests of male students at the site while continuing to offer an exemplary freshman physics experience to all students.
5. To provide positive social change for the students at rural schools by strengthening STEM skills and interest leading to a meaningful career in a STEM field.

Timeline and Evaluation

The PhET Simulation Lesson Planning guide will be given to the school’s freshman physics teacher in June and asked to review it and the PhET web site including its simulations for physics and its teacher resources. The researcher will meet in August at the start of the following school year to develop the first lesson plan. The second meeting between the teacher and the researcher will take place no more than two weeks after the first simulation lesson and formative assessment has been delivered. Successive pre-post meetings will take place until four PhET simulations have been implemented and data collected. In May the FCI will be given to all freshmen physics students, data will be analyzed and compared to the previous year’s FCI scores. The gender effect will be analyzed and compared to the gender effect realized by the previous research to see if male students showed any improvement following simulation instruction.

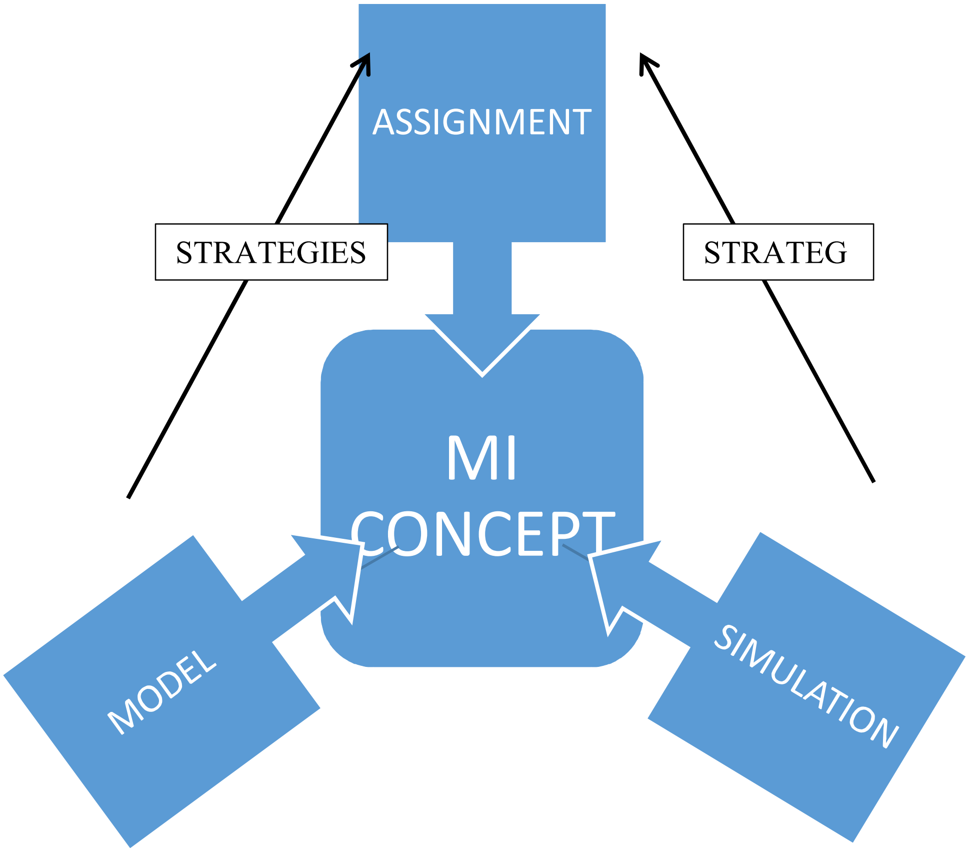

Figure A1. Framework for development of a concept using computer simulation within the MI curriculum. Arrows indicate implementation of strategies set.

Arrows project from all three components of the lesson indicating that each component is focused on a specific modeling concept. Based on the correct model and the simulation used, strategies can be selected to help guide the development of the assignment. Some possible strategies could include but are not limited to:

a) Create a game scenario that encourages students to investigate specific components of a phenomenon.

b) Require students to develop multiple explanations and representations of the same phenomenon.

c) Direct students to describe, experiment, analyze, defend, and generalize a phenomenon.

d) Include dialog between students that encourages them to productively discuss a specific phenomenon.

PhET Simulation (PS) and Hands-On (HO) Activities Within the MI Curriculum

Unit 1: Scientific Thinking in Experimental Settings

HO: Spaghetti Bridge Lab

Unit 2: Particle Moving with Constant Velocity

PS: Moving Man

HO: Buggy Motion Lab

Unit 3: Uniformly Accelerated Particle

HO: Wheel Lab

Unit 4: Free Particle Model or Balanced Force Model

PS: Forces and Motion

HO: Bowling Ball on Ramp

Unit 5: Unbalanced Force (Net Force) Particle Model

PS: Masses and Springs

HO: Modified Atwood's Machine Lab

HO: Friction Lab

Unit 6: Particle Motion in Two Dimensions

PS: Projectile Motion

HO: Projectile Motion Analysis Using Video Motion Capture

PS: Pendulum

Unit 7: Central Net Force Particle Model

PS: Ladybug Revolution

HO: Circular Motion Lab

PS: Masses and Springs

Unit 8: Energy Storage and Transfer Model

PS: Energy Skate Park

HO: Hooke’s Law Lab-Elastic Energy Extension

HO: Energy Transfer Lab 1: Elastic Energy to Kinetic Energy

HO: Energy Transfer Lab 2: Elastic Energy to Gravitational Energy

Unit 9: Impulsive Force Model

HO: Cart Explosions Lab

Appendix B: Letter of Cooperation

XXXXXX High School
XXXXXX
[redacted] AZ XXXXX

April 7, 2014

Dear Devin A. Ditmore,

Based on my review of your research proposal, I give permission for you to conduct the study entitled Modeling Instruction in the Freshman Physics Classroom within XXXXXX High School. As part of this study, I authorize you to collect Force Concept Inventory pre-posttest scores for the 2016 and 2017 cohort classes. I understand that all data collected will be de-identified.

I confirm that I am authorized to approve research in this setting.

I understand that the data will remain entirely confidential and may not be provided to anyone outside of the research team without permission from the Walden University IRB.

Sincerely,

XXXX

XXXX
Principal
[redacted]
XXX-XXX-XXXX